Ain Shams University
Faculty of Engineering
Department of Architecture

Utilizing Algorithms in Designing Museums

By

Nouran Khaled Sayed Morsi
B.Sc. Architecture, Faculty of Engineering – Ain Shams University, 2010

A thesis Submitted to the Faculty of Engineering for Partial Fulfillment of requirements for the degree of
Master of Science in Architecture

Under Supervision of

Prof. Dr. Yasser Manssour
Professor of Architecture and Environmental Control
Faculty of Engineering – Ain Shams University

Dr. Hazem Mohamed El - Daly
Assoc. Professor
Faculty of Engineering – Ain Shams University

Cairo, Egypt
2014

Ain Shams University
Faculty of Engineering
Department of Architecture

Researcher Name: Nouran Khaled Sayed Morsi
Thesis Title: UTILIZING ALGORITHMS IN DESIGNING MUSEUMS
Degree: Masters of Science in Architecture.

Examiners Committee

Name, Title and Affiliation	**Signature**
Prof. Ahmed Fareed Gamal-El Deen Hamza Professor of Architecture – Head of Department of Architecture Shoubra Faculty of Engineering- Benha University	
Prof. Shaimaa Mohammed Kamel Professor of Architecture Faculty of Engineering- Ain Shams University	
Prof. Yasser Mohamed Mansour Professor of Architecture and Environmental Control Faculty of Engineering- Ain Shams University	

DATE: / / 2014

بسم لله الرحمن الرحيم

" و قل رب زدني علماً "

صدق الله العظيم

To

Mom, Dad, and Brother

For all your Support and Unconditional love

My friends

And

My colleagues of

FEDA 2010

Statement

This thesis is submitted to Ain Shams University for the degree of Master in Architecture. The work included in this thesis was accomplished by the author at the Department of Architecture, Faculty of Engineering; Ain shams University from 2011 to 2014. None of this thesis parts has been submitted for a degree or a qualification at any other university or institute.

Date: / /2014

Signature:

Name: Nouran Khaled Sayed Morsi.

Faculty: Faculty of Engineering – Ain Shams University.

Acknowledgement

First and foremost, I thank God for everything and for enabling me to go through this path and allowing me to do this research.

The Author wishes to express appreciation for all those who made this thesis possible. Special Thanks to ***Professor Dr. Yasser Mansour*** and ***Dr. Hazem El-Daly***, who supported the development of this research, with their intensive help, valuable advice, constant effort, and their continuous encouragement.

The Author also wishes to make a special reference to ***Professor Dr. Ahmed Ali El Khateeb*** without his stress on the value of Scientific Researches the research could not have been exist, ***Assistant Professor Dr. Sabah Soliman*** for her help in the research writing, ***Assistant Professor Dr. Magdi M. Ibrahim*** for helping me to choose this field of research, and ***Assoc. Professor Dr. Ola E. Bakry*** for her support and proofreading.

The Author also thanks ***Assoc. Professor. Arch. Manar Mohamed*** and ***Assoc. Professor. Arch. Ayman A. Fareed*** for their support along the academic and research period.

Abstract

This study aims to highlight the effect of utilizing the Algorithmic design methodology in the Architectural design ofMuseumbuildings.The changes happened to visitors’ behavior, as a result of the modifications introduced to the exhibition hall arrangement, are observed and analyzed using computer application programs, such as Rhinoceros program and Grasshopper plug-in. These programs depend on applying the common algorithms used in the Architectural design including (Cellular Automata, Swarm Intelligence) for the arrangement of artifacts in the exhibition halls, in addition to the Space syntaxtheory,which is also based on algorithms, for analyzing the visitor’s movement. By using this computer application from the beginning of the design process, designers may achieveproper solutions for exhibition in museum spaces, thus revealing the cultural message of the museum.

Keywords: *Museums – Culture Message – Visitor’s Experience – Exhibition Hall – Algorithms.*

Summary

The design process imposes that the designer should deal with many constraints, in addition to studying the different elements that affect the design, in order to reach the best design solution, by using advanced tools. As there is a rapid development in the methods of architectural design, by using computer application programs, the architect has to deal with these programs using different methodologies, which differ according to the required application. Accordingly, these methodologies should be improved to suit the required design. This has made the design process depend mainly on an advanced methodology, which aims to obtain a number of solutions, and select between them, to reach an appropriate solution.

Based on that, the design process has been developed for many types of buildings, to depend partially or sometimes totally on application of different methodologies, to reach an integrated architectural product. Museum buildings are of these buildings, which depends on a manual design methodologies that make the development in its design methodologies became a need in this digital age.

This research is concerned with how to reach a design concept, which emphasizes the content and the objectives of the museum. The ability of the visitor to perceive the cultural and scientific content of the museum is illustrated, which is considered the main goal of any museum. According to that, the responsibility falls on the designer to study the type of the museum, and the types of its exhibits, presenting a certain cultural messege which is required to be revealed to the visitors. In addition, the designer has to be concered with the different charactaristics of the visitors and their behavior inside such type spaces, which affects the whole design.

The research also addresses one of the advanced techniques of digital design using algorithms, and its effect on the architectural design of museums. The research concentrates on the possibility of reaching a new methodology of designing museum exhibition halls, and the way to comply with the museum message. This in addition to studying the way of arranging exhibits digitally, and its relation to the visitors' behaviour, which shall be shown in details through a digital design methodology and an application in designing the exhibition hall using algorithms.

Table of Contents

List of Figures

Chapter 1: Introduction to Museum Building.

Chapter 2: Museum Exhibition Hall Design.

Chapter 3: Design by Algorithms.

Chapter 4: Architectural design of Museums using Algorithms.

Chapter 5: Exhibition Hall Arrangement using Algorithms.

Conclusion.

Recommendations.

List of Tables

Chapter 1: Introduction to Museum Building.

Chapter 2: Museum Exhibition Hall Design.

Chapter 3: Design by Algorithms.

Chapter 4: Architectural design of Museums using Algorithms.

Chapter 5: Exhibition Hall Arrangement using Algorithms.

Conclusion.

Recommendations.

Introduction

During the recent decades, new digital design methods and generative tools have taken their place in the architectural design utilized by the computer as a design tool. In 1963, Ivan Sutherland has proved that computer programs could be used for modeling and drafting. In the 20^{th} century, architectural products became unimaginable without this digital tools and technologies powered by computer after the developments followed the Turing machine in 1936. New methods of design have been introduced, which provides more developed solutions to the relation between building designs, forms, and the environment. After few years, the architectural design by computer became more advanced than the CAD software, by using powerful modeler softwares based on codes and scripts, such as Algorithms have envolved. As a result, the field of architectural design has become more advanced by applying this technology in the design stages, consequently the architectural concept has changed from Technological Architecture to Computational Architecture. Using Algorithms in the initial design stages has become a prerequisite for generating superior architectural product with more effective design solutions. Many types of buildings have been affected by this computational design approach, especially public buildings as museums.

According to the Greek mythology, “Museum” is “The seat of Muse”, or “The place of Inspiration”, or “The place where the philosophers meet for discussing issues”. It was developed over centuries until it became a separate building, which reflects the artistic sense and stimulates inspiration. Museums are considered as one of the main civilization marks, and an evidence of the scientific and technological progress. In addition, it is a reflection of the new revolution in the architectural field these days; as their architectural design has been influenced by technological development. An example of a museum designed using computer modeling systems, which was designed using aerospace software (CATIA) is Guggenheim Bilbao by Frank. O. Gehry. The computer modeling system was used to develop and coordinate building systems by mapping its curved surfaces.

In the design of any museum, the challenge is to produce a new form in combination with a successful functional plan, which reflects the museum design concept and its cultural message.Thus, creating a suitable space to present artifacts in an aesthetic way, taking into account the museum visitor’s experience. The museum architectural design used to be limited to form and functional plan according to an architectural program, disregarding the exhibition, which is designed by the museum curators. Recently, architects have become more specialized in the exhibition process, and called as “Museographers”. Exhibition halls are considered the most substantial spaces in the public zone, and the value of any museum is determined by the value of information to deliver during the museum visit to capture visitors' approbation. In order to design a museum plan, the relation between the three major museum zones (public – administration – exhibits service) should be well defined. In addition, they have to make visitors feel more comfortable during their visit, which highlights the importance of studying the visitor's movement pattern,as a result, the museum building success comes to the architect.

Through this study, the relation between the exhibition hall design, the exhibits arrangement inside it, and its effect on the museum visitors, in addition to their interaction with the built environment is discussed. Studying the effect of utilizing Algorithims in the Architectural design of Museum buildings, with the help of Algorithmic design methodology, and generative design tool; new solutions for the hall arrangement applied on a virtual museum hall are highlighted through the application.

• Research Problem

"Proofing that The Design of Museum building, especially Exhibition Hall design, could be achieved by using Generative Algorithmic design".

• Research Objectives

Main Objective:-

Highlight the effect of utilizing the Algorithmic design methodology and techniques in the design of museum buildings, especially in the exhibition hall arrangement and the visitor's behavior

Secoundry Objectives:-

- The museum cultural message, which affect the exhibition strategies and techniques, and consequently the museum visitor's experience.
- The different types of museums, and its relation to the exhibited artifacts.
- The computational design techniques such as algorithms, and its relation with the architectural design of museums.

• Research Methodology

The research discusses the Architectural design of museums based on a computer application program by Algorithms in:

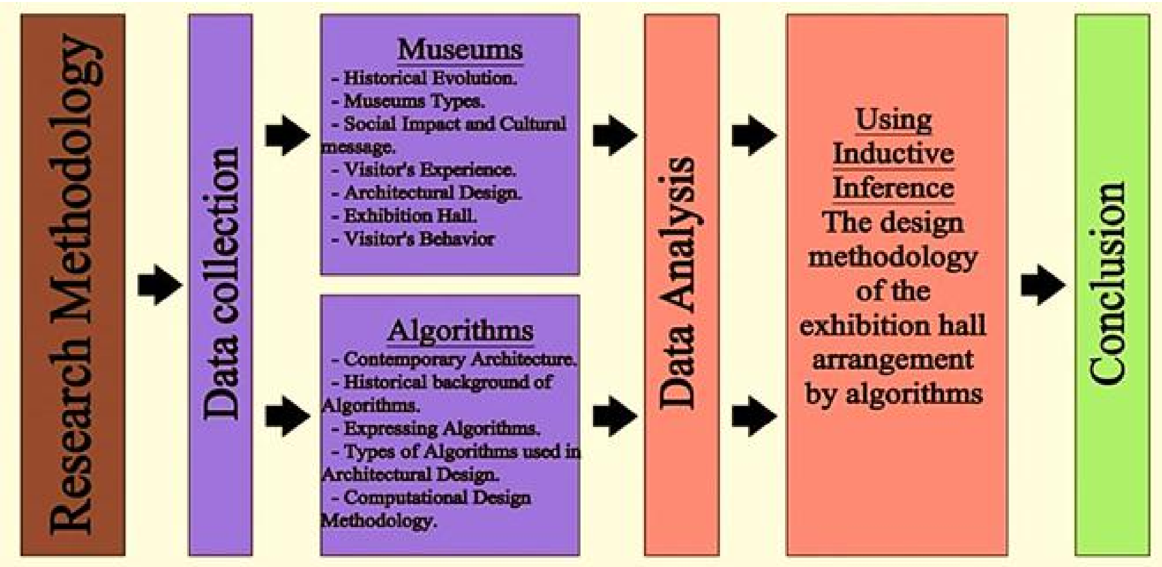
1. **Data collection.**
   Using an ***analytical methodology*** in assessing the architectural design of museums, through studying the museum spaces and the expected types of movement.In addition, the interaction between the new computational design methods based on algorithms and the architectural design, through ***a literature survey***.

2. **Data analysis.**

   Using ***inductive inference*** to conclude the methodology of the exhibition hall arrangement by algorithms, through which the museum cultural message will be achieved, supported by an application for the presented design methodology.

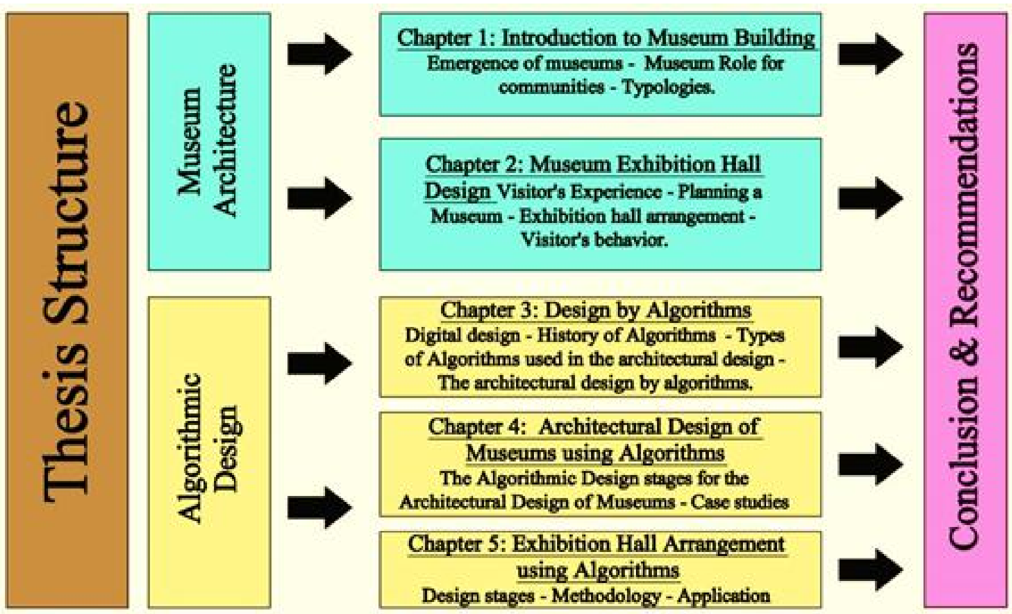
3. **Conclusion.**

   Finally, concluding how to design museum spaces, especially exhibition hall, will be influenced by applying algorithmic design. Recommendations are set for the design process of the museum, thus enabling designers to achieve the museum cultural message.



- **Thesis structure**

The research consists of ***five chapters*** as follows:



* ***Chapter 1 – Introduction to Museum Building.***

  This chapter discusses the emergence of the word museum, in addition to an explanation of the social cultural changes from the B. C until the 20^{th} century, that effect on the evolution of museum buildings is reviwed. Then, the museum role for society, in addition to the main types of museums will be highlighted, which forms the museum cultural message.

  Chapter 2 – Museum Exhibition Hall Design.

  This chapter presents the relation between the main contexts that forms the museum visitor's experience, and its relation with the design of museum spaces, especialy exhibition halls. In addition to the relation between the visitor's movement and the exhibits arrangement.

* ***Chapter 3 – Design by Algorithms.***

  This chapter includes the new digital design techniques applied in the field of architecture, especially algorithms. It also discusses the history of algorithms, how to express algorithms, the main types of algorithms used in the architectural design, and the architectural design by algorithms supported with some examples for different builings.

* ***Chapter 4 – Architectural design of Museums By Algorithms.***

  This chapter discusses the design of museums by algorithms, and the main design stages algorithms could be applied in. in addition, three case studies for modern museum designed based on algorithms.

* ***Chapter 5 – Exhibition Hall Arrangement By Algorithms.***

  In this chapter, a practical explanation for utilizing algorithms in the design of exhibition halls, through an automaded design methodology, and verified through an application to explain how this methodology could be implemented digitaly.

* ***Conclusion & Recommendations.***

  Results and Recommendations are set to guide the designer through the design process of museums in order to achieve their cultural message.

Chapter 1: Introduction to Museum Building.

1.1. Introduction.

Museums became one of the most important building types, not just for the architect life work, but also for society members. Museums are an evidence of civilization; they reflect the cultural lineaments of communities.

Museums play a significant role towards the different visitors from other countries. Before recounting its significant roles, the origin of the word "Museum" should be defined first, and then its historical evolution from being a small part of buildings like schools or libraries in the B.C times, a cabinet of curiosities in palaces from the 14th century to the 18th century, to a separate building that has a special architectural characteristics as it is nowadays.

1.2. The Emergence of Museum.

The ancient Greek civilization was based on some certain beliefs like the ancient Egyptian civilization. It was depending on believing in the existence of gods. According to the Greek mythology Zeus (The God of Sky and Thunder) was the “King of Gods”, his wife Mnemosyne (The Personification of Memory) and their nine daughters were “The Nine Muses”, *Calliope (Epic Poetry), Clio(History), Erato(Love Poetry), Euterpe(Music), Melpomene (Tragedy), Polyhymnia (Hymns), Terpsichore (Dance), Thalia (Comedy), Urania (Astronomy)*. The word “Muse” means “The protector of Arts” according to the Greek mythology, and the word Mouseion “the seat of Muse” refers to the places of meditation and philosophical discussions in the Roman era(1).

1.2.1. Linguistic definition

Arabic definition

Museum definition in language is the place of preserving the art work’s and archaeologies, plural is Museums. The word derived from the wonderful or precious made piece. It is presented as a gift to reach someone or something(2).

English definition

Museum, as a noun means"*A building where important cultural, historical, or scientific objects are kept and shown to the public*"(3).

Latin definition

Museum word means the seat of the muse, or the place where the philosophers meet discussing issues(4).

(1) Online Etymology Dictionary, www.etymonline.com/index.php?term=muse&allowed_in_frame=0
(2) البستانى، بطرس، القطر المحيط،ص171
(3)Longman Dictionary of Contemporary English.
(4)H.H, B.C, “*The New Encyclopaedia, Macropaedia*”, volume12, P (657).

1.2.2. Scientific definition

In the past museums were the places of meditation and philosophical discussions in the Roman era. The museum was an indication of luxury, promoting spirits, sublimit the sense of beauty, appreciating the artistic value, and liberation from church domination of thoughts. The visitors were from princes, emperors, and bishops.

Nowadays museums are known as a place for preserving historic pieces, appreciating the artistic icons, and recording the human science invents. The visitors of museums now are from every place, different cultures, different ages, and coming for different purposes.

"*Museums are no longer just a place for art cognoscenti to gather and admire art; on the contrary the typical museum of the 20th century became a building combination of destination site and tourist attraction. Such a place aside from showing original art now provides places to eat, to buy souvenirs and reproductions, and to view virtual showings of real art in electronic formats*"(1).

"*The museum is an institution that assembles studies and conserves objects representation of nature and man in order to set them before the public for the sake of information, education, and enjoyment*"(2).

1.2.3. Museum definition according to ICOM(3)

"*A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment*"(4).

1.3. Historical Evolution of Museums Architecture.

1.3.1. Museums from the Ancient times to 17th century.

Although there are many differences between the museum concept of today and what it was in the past; but these differences helped in understanding how much did the ancients interested in arts and preserving heritage.

A. The Museum Ideology.

The idea of establishing a museum or express it goes back to the B.C time. The museum was an important feature at schools and ancient libraries. The role of museums at the time confined to the educational role. Museums were spreading knowledge and history through a small hall in school and library full with the cloned pieces used for educational purposes, as explained in a tablet discovered in Babylonian (Iraq now)(5).

(1) Kliment, S.A, "*Building type Basics for museums*".
(2)Ibid, H.H, B.C, P (649).
(3) **ICOM:** International Council of Museums.
(4)ICOM, 21st General conference.
(5)Lewiss.G, "*The history of museums*", Encyclopedia Britannica.

The spread of Christianity during the medieval times in Europe made some changes in the religious ideology and culture; which gave the church a great importance to princes and statesmen. The art collections were preserved by princes in palaces or in the church safes, these treasures were very important for the economic purposes, as they were used for funding armies during the war, and their clones used for trading.

As a result of the connection that links Europe with the other countries by the sea, harbors like Lombardy and Tuscany on the Mediterranean sea formed a continuous communication between countries and the church in Rome, because of the trade traffic around the world depending on selling collection opened between them. The transfer of antiques was very common in Europe at this time. The transferring became obvious after the four famous bronze horses moved from Constantinople to St Mark's Basilica in Venice during the Crusades in the 13 th century, as shown in figure (1.1), these horses were called after that *The Triumphal Quadriga* or *Horses of St Mark's*(1).

Figure 1.1 The Triumphal Quadriga
Source:www.ancient.eu.com/news/4814/

The word Museum was first used in the 15th century in Europe for describing Lorenzo De' Medici's works in Florence, by the 17thcentury, it was used to describe the European artists work like Ole Worm.

The passion of classical heritage and collecting antiques for princes, nobles, and merchants became more than before the Renaissance period (1400-1650), and spread all over the European countries. Many palaces turned into museums containing manuscripts, antiques, natural history pieces and paintings for the most famous painters like Antony Van, Leonardo DA Vinci, and Raphael were presented in separate museums. The movement of making these collections started in some European countries like France, England, Spain, and Germany. More than 1500 paintings and some pieces of art back to the ruling era of Frances II (1515-1547) were transferred to the grand gallery in Louver to present to public during occasions. The royal collection of the Holy Romanian emperor Charles V and other Italian art works are presented now in Prado museums in Madrid(2).

(1) Freeman. C, "*The Horses of St. Mark's: A Story of Triumph in Byzantium, Paris, and Venice*".
(2) عاصم، أيمن, "إدراك الفكر التصميمى للإتجاهات المعاصرة فى عمارة المتاحف"

B. Museums of This Era.

During the ruling time of the Pharaoh Akhenaten (1335-1353 B.C) a big library was built as he requested in Tal El Amarna region, it was full of antiques and precious collections[(1)]. Another school was found in the ruins of Babylonian city which was preserving some items in their small educational museum[(2)].The rare collection found in the Chinese emperor's tombs reflecting their care of the arts. A large number of antiques, metal work, glass work and paintings were discovered in these tombs, guarded by statues of terracotta warriors which presented now in the Museum of Ch'in figures[(3)].

The emperor's collections at the medieval time in Europe were preserved in the emperor's castle or palace. After the emperor's death the collections shared between the nobles, princes, and the church's bishops[(4)]. An example of that was the collection of the emperor Charlemagne[(5)].

According to the ideology in Renaissance times, many kings transferred their palaces and castles into museums. The palace of Buda became a museum of paintings, and also the Szombathely castle became a museum of the Romanian antiques. In the green vaults of the Dresden palace[(6)], shown in figure (1.2)& (1.3), samples of scientific materials and a unique variety of exhibits from the period of baroque to classicism were presented[(7)], shown in figure (1.4)&(1.5).

Figure1.2 Dresden palace – Germany
Source:www.dresden.de/dig/en/sightseeing/sehenswuerdigkeiten/historische_altstadt/residenzschloss.php

(1) Ibid,عاصم، أيمن
(2)Abd El Rehem, M. M, "*Museums and Architecture*".
(3)Ibid. Lewiss.G.
(4) Ibid.
(5)**The emperor Charlemagne:** ruled the Romanian empire (800-814), and the king of Franks (768-800). He had number of palaces in Nijmegen and Anglhaim, these palaces were containing many treasures, columns, golden and silver lights, and bronze doors, most of these divided between the church and some princes.
(6)**Dresden palace:** rebuild by King Augustus II the Strong after the fire in 1701on the Baroque style, The Dresden palace now housing five museums the Historic Green Vault connected with the New Green Vault, the Coin Cabinet, the Collection of Prints, Drawings and Photographs and the Turkish Chamber.
(7)en.wikipedia.org/wiki/Dresden_Castle#cite_note-3

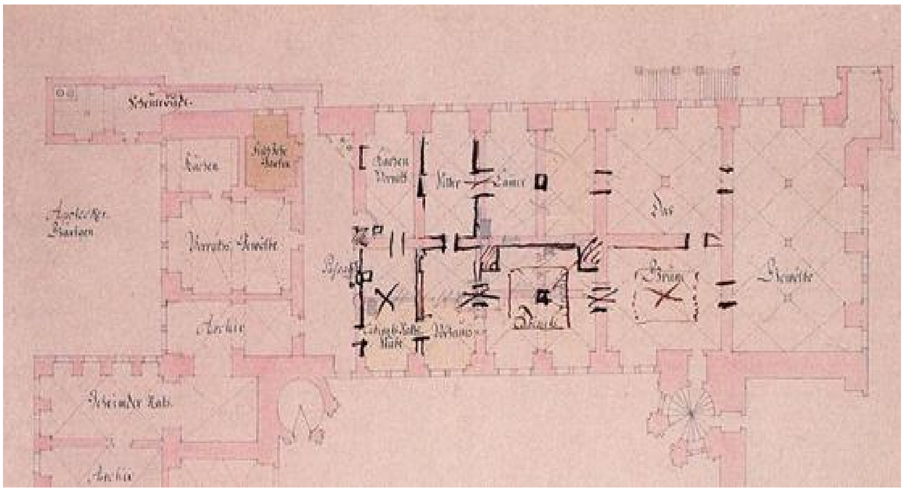


Figure1.3 Plan of the ground floor of the west wing of Dresden Castle with handwritten notes by Augustus the Strong in connection with the expansion of the Green Vault
Source: Kunstverlag. D, "*The Baroque Treasury at the GrünesGewölbe Dresden*".

Figure1.4 Hall of treasures in the Green Vault 1904
Source: atlasobscura.herokuapp.com/places/green-vault

Figure1.5 Hall of treasures in the Green Vault now
Source: www.skd.museum/en/museums-institutions/residenzschloss/gruenes-gewoelbe/index.html

1.3.2. Museums from the end of 17th century to 19th century.

A. The Museum Ideology.

At the end of the 17th century, the royal and noble passion for collection increased. They kept these collections in what so called "Cabinet of Curiosities"(1), which contains lots of paintings, antiques and some pieces of natural history(2).

(1)Impey.O.R.,and MacGregor. A., "*The origins of museums: the cabinet of curiosities in sixteenth and seventeenth century Europe*".
(2)Ibid, H.H, B.C, P (659).

Most of Florence, Vienna, and the Vatican collections are transferred to other museums, known now as the most important museums around the world. These collections were just presented to the nobles, as a part of luxury, promoting spirits, sublimit the sense of beauty, appreciating the artistic value, and liberation from the church domination of thoughts[(1)].

The 18th century is considered to be the onset of the public museums in Europe[(2)]. Most of the 18th century museums started with the 16th century galleries and cabinets. Many reasons helped museums to grow up in this time including:

- The Diminution of high class's power and church domination.
- The interest of public in arts and culture after the Industrial revolution in this century.
- The new development in science, technology, and arts.
- Discovering the Americas, and converting it to English colonies.
- The American museum movement started after the civil war.

In this time, the museums were still limited to the aristocratic class, but opened few days for public to visit it[(3)]. After the French revolution in 1789, the society concepts changed, which gave the public and the middle class more social rights, and affected the governing ideologies and the social life in Europe.

B. Museums of This Era.

New museums appeared at the end of the 17th century in Europe, the Vatican collection was presented for public in museums as:

I. The Ashmolean Museum opened to the public in 1683, England, shown in figure (1.6).
After the property of Tradescant's collection was moved to Elias Ashmole, and then he transferred it to a new building in Oxford University, which build specially to host this collection and named the Ashmolean Museum. The Ashmolean museum considered as the first old museum built with the concept as nowadays and the first university museum[(4)].

Figure 1.6 The Ashmolean Museum
Source: www.ashmolean.org/

(1)Ibid,Abd El Rehem, M. M
(2)Ibid, H.H, B.C, P (659).
(3)Ibid,عاصم، أيمن
(4) Ibid. Lewiss.G.

II. The Capitoline museum in 1734, as shown in figure (1.7) & (1.8).

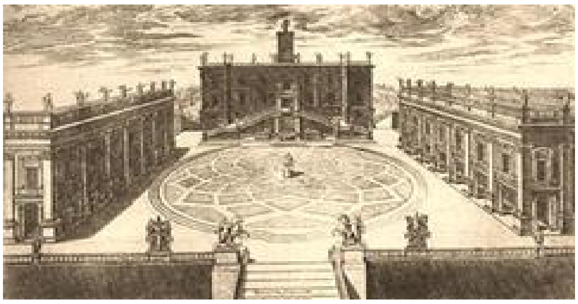


Figure1.7 Michelangelo's design for Capitoline Hill, now home to the Capitoline Museums 1568.
Source: Morgan, C. H. "*The Life of Michelangelo*".

Figure1.8 The Palazzo dei Conservatori is one of the three main buildings of the Capitoline Museums.
Source: en.museicapitolini.org/

III. The Vatican Pio-Clementino museum of sculptures in 1772.
This museum collection contained a lot of the antique works of the Renaissance, now the museum hosts the work from Greek and Roman time sculptures(1).

The movement of turning palaces into museums increased at this time, from those museums:

I. The Louvre museum(2), see figure (1.9).

Figure 1.9 The Louvre Palace.
Source:www.louvre.fr/

II. The British museum was established in 1753 in England, shown in figure (1.10).

(1) Ibid. Lewiss.G.
(2) Louver Museum: it was built in the 12th century, during Philip II ruling time, in 1682 it was turned from Louver palace to a museum by Louis XIV to present his royal collection, and he moved to live in Versailles palace.

Figure 1.10 The Entrance to the British Museum in London, England.
Source: www.britishmuseum.org/visiting.aspx

The presented collection in the British museum at this time was collected by Sir Hans Sloane(1)his collection consisted of specimens, natural history pieces from Jamaica, ethnographic, numismatic, and art materials. Sloane's collection was about 100,000 pieces; this collection became the core of the museum. Other collections were added to the British museum by Sir Robert Cotton and Robert Harley it was mainly containing manuscripts(2).

III. The Charleston Museum, South Carolina, 1773.

The museum was just for the natural history at this time(3), as in figures (1.11) & (1.12), the Charleston Museum is known as the oldest American Museum in records(4).

Figure 1.11 The Charleston Museum.
Source:
www.charlestoncvb.com/visitors/tripplanner/what_to_see_do~3/attractions~31/museums~48/the_charleston_museum_~22.html

Figure 1.12 Becoming Americans and the low country history halls.
Source: www.charlestonmuseum.org/exhibits-permanent

IV. The Peale Museum is known as (Municipal Museum of Baltimore), Baltimore, Maryland, USA, 1814.

---

(1)**Sir Hans Sloane**: (16 April 1660 – 11 January 1753) was an Irish physician and collector, notable for bequeathing to the United Kingdom which became the foundation of the British Museum.
(2) Ibid. Lewiss.G.
(3) Ibid.
(4)www.charlestonmuseum.org/about

V. Calcutta Museum, India, 1784.The museum collection based on the Asiatic Society of Bengal's collection.

VI. Indonesian Museum or the Central museum of Indonesian Culture, Indonesia, 1778.The Batavia Society of Arts and Science's collection was the base for it in 1778[(1)].

New museums opened around the world during the 19th century, for example:

I. The Metropolitan museum of art, Philadelphia, 1870-1874,designed by Calvert Vaux and Jacob WreyMould, shown in figure (1.13).

Figure 1.13 The Metropolitan Museum.
Source: www.metmuseum.org/visit

II. American natural history museum, New York City, 1869, shown in figure (1.14).

Figure 1.14 American natural history Museum.
Source: www.amnh.org/

III. Argentine museum of natural science in Buenos Aires, South America, 1812.

IV. Brazil's national museum, Rio de Janeiro, opened to the public in 1818.

V. National museum of natural history in Santiago, Chile, 1830.

VI. Zoological museum in Cape Town, South Africa, 1825.

VII. The Australian Museum, Sydney, 1827.

(1) Ibid. Lewiss.G.

VIII. The Egyptian museum or the museum of Egyptian Antiques, Cairo, established in 1835 and moved many times till the new museum in Tahrrir square built in 1902. The Egyptian museum contains most of the discovered Pharaonic artifacts, shown in figure (1.15).

Figure 1.15 The Egyptian museum, Cairo, in 1896.
Source: www.sca-egypt.org/eng/MUS_Egyptian_Museum.htm

New museums found their way in the 19th century and opened in many countries, Ukraine, Copenhagen, Denmark, France, United Kingdome, and Germany[(1)].

The architectural style of this period museum was the Neo Classical, which was prevalent for about two centuries in Europe. Buildings were looking like palaces and the huge public buildings before that, as the buildings of the Renaissance period. In the 18th century the museum building design was as follows [(2)]:

- Plan:
  They used the cross plan as general and a dome in the center surrounded by exhibition halls covered by vaults.

- Elevations:
  Solid elevations were used in case of using the top lighting. The main elevation was full of column, natural forms, with big entrance.

- Exhibitions:
  Natural history pieces, books, antiques, monuments, and manuscripts were the most common exhibits in the museums. Very traditional way of exhibition used with a simple record for each piece.

- Lighting system:

  The source of light was always natural light through top openings, so they used the clearstory lights (clerestory lighting), and large numbers and areas of windows in elevations to get the maximum advantage of the natural light.

(1) Ibid. Lewiss.G.
(2) صلاح الدين، خالد، "عمارة المتاحف"

1.3.3. Museums from 20th century to present and the future of museums.

A. The Museum Ideology.

Since the beginning of the 20th century, a new generation of museums had started. Many factors affected the museums of this period, starting with the World War I, in which new museums had been built, especially in Germany to glorify the Nazis figures and the war's soldiers.

After that, new museums had been established to glorify The Three Russian Revolutions. New type of museums appeared like "The Memorial Museums", personal stuff about the famous characters was preserved in these museums(1).

A lot of ruins resulted from The World War II, especially in Europe, most of the European countries used these ruins during its reconstruction, and they had been placed in the museums to be preserved after the war(2). The museums before this period were suffering from the domination of politics and government men. After the war museums became an independent society after the expansion of democracy all over the world(3).

Later, A rise of new generation of architects with new vision of architecture of this century, like Le Corbusier, Mies Van Der Rohe, Frank Lloyd Wright, and others. Each architecture school adopted a different ideology of the other school. Designing by form or by function was the main ideology at this time, all of that affected the architectural products. The new architectural school leaders were searching for what makes their work a landmark in the history of architecture, so they started with the museum buildings, for its leading educational and cultural role(4).

In addition, The extension of American and European colonies politically and economically(5), which extended the interest in the European life, arts and museum culture into many areas.

The industrial development in USA and Europe and the scientific & technological progress(6), made the museum architecture easy to be executed. New techniques were used like (artificial lighting systems, exhibiting systems, circulation systems, structural system, and finishing materials).

According to the great role played by museums in culture, education, touristic, and in interment with different typologies to satisfy its visitor's needs new spaces were added to the functional program of museums including:

(1) Ibid. Lewiss.G.
(2)Ibid, H.H, B.C, P (660).
(3)Ibid,عاصم، أيمن
(4)Ibid,Abd El Rehem, M. M
(5)Ibid, H.H, B.C, P (660).
(6)Ibid, H.H, B.C, P (660).

- Culture spaces: library, temporary halls for exhibitation, and out doorexhibition.
- Preservation and restoration rooms: labs, and workshops.
- Educational spaces: lecture halls, showrooms, and conference hall.
- Entertainmental spaces: resturants, cafeterias, and stores for gifts and souvenirs.

These new spaces such as restaurants, shops, and cafeterias, not just for entertaining, but also as funding source for museums, to be used in enlarging the museum collections by buying new original items which costs a lot, or for building new museums. This economic problem appeared with the Russian state of the museum, after the collapse of the Soviet Union, museums had its own budget, sooner it became so hard for the government to save money for developing museums, so they began to make museums fund itself after the public fund had fallen[(1)].

During the 21st century, many museums took its place all over the world; as a result of the paradigm shift in the digital design. The result of the interference between the different scientific branches was the development in the design ideology of the museum. This shift offered the architects new solutions for their problems between designing an imaginary form and the functional needs for spaces. Accordingly, the field of architecture design became more advanced; as they moved to use this technology in the design stages.

New architects affected the museum design during the 21stcentury like Frank Gehry, Zaha Hadid, Daniel Libeskind, Jean Nouvel, and other. The new trends and technology used in the design stages changed the design ideology along century.

This new technology included new ways of presenting artifacts, lighting techniques, monitoring, control, and virtual visits for the museums. The virtual museums became more preferable for those who cannot visit museums, which affected the architecture design of the museum spaces, serving for both real and virtual visitors[(2)]. The movement control inside the museum became easier to be solved after the new solutions presented by the digital technologies, but the virtual movement still need another way to be solved.

[(1)] Ibid. Lewiss.G.

[(2)] راشد، هيثم فاروق، "دور الواقع الافتراضي في تصميم المتاحف"

B. Museums of This Era.

I. The State Hermitage Museum, The winter palace, St. Petersburg, 1732-1917, shown in figure (1.16).

Figure 1.16 The State Hermitage Museum, The Winter Palace, St. Petersburg, Russia.
Source: www.saint-petersburg.com/museums/hermitage-museum/

II. The central armed force museum, Moscow, 1924, shown in figure (1.17).

Figure 1.17 The central armed force museum, Moscow.
Source: www.moscow.info/museums/central-armed-forces-museum.aspx

III. The Deutsche Museum, Munich, 1925, shown in figure (1.18).

Figure 1.18 The Deutsche Museum, Munich.
Source: www.deutsches-museum.de/en/information/museum-courtyard/

IV. Museums by Le Corbusier

- The Museum of unlimited Growth, 1939, shown in figure (1.19).

Figure 1.19the Museum of unlimited Growth in 1939.
Source: - Kaynar. I., "*Visibility, movement paths and preferences in open plan museum*".

- Sanskar Kendra Museum, Ahmedabad, India, 1956.
- The National Museum of Western Art, Tokyo, 1957, shown in figure (1.20).

Figure 1.20 The National Museum of Western Art, Tokyo.
Source: www.nmwa.go.jp/en/

V. Museums by Frank Lloyd Wright

- The Guggenheim Museum, Manhattan, New York City, 1943, shown in figure (1.21).

Figure 1.21 The Guggenheim Museum, Manhattan, New York City.
Source: www.greatbuildings.com/cgi-bin/gbi.cgi/Guggenheim_Museum.html/cid_cr1037_b.htmlandwww.guggenheim.org/new-york/about/guggenheim-images

The new technologies affected the architectural product and the result was new museums with a different concept of design like:

VI. Museums by Frank Gehry

- Guggenheim Bilbao Museum, Spain, designed by Frank Gehry, 1997, shown in figure (1.22).

Figure 1.22 Guggenheim Bilbao Museum, Spain.
Source:www.guggenheim.org/bilbao

- Guggenheim Abu Dhabi, UAE, designed by Frank Gehry, shown in figure (1.23).

Figure 1.23 Guggenheim Abu Dhabi, UAE.
Source:www.guggenheim.org/abu-dhabi

VII. Museums by Daniel Libeskind

- Jewish Museum, Berlin, built in the 18th century and a building attached to it by Daniel Libeskind in 1999, shown in figure (1.24).

Figure 1.24 Jewish Museum, Berlin.
Source:www.archdaily.com/91273/ad-classics-jewish-museum-berlin-daniel-libeskind/

- Imperial War Museum North, Manchester, England, 2002, shown in figure (1.25).

Figure 1.25 Imperial War Museum North, Manchester, England.
Source:openbuildings.com/buildings/imperial-war-museum-profile-9858

- Denver Museum Of Modern Art, USA, designed by Daniel Libeskind, 2006, shown in figure (1.26). And the new extension of the museum designed by Frederic C. Hamilton.

Figure (1.26) Denver Museum of Modern Art, USA.
Source:www.arcspace.com/architects/Libeskind/denver2/denver2.html

VIII. Museums by Zaha Hadid

- MAXXI – National Museum of the 21st Century Arts, Rome, Italy, 1998 to 2009, shown in figure (1.27).

Figure 1.27MAXXI – National Museum of the 21st Century Arts, Rome.
Source:www.zaha-hadid.com/architecture/maxxi/

- Riverside Museum or the Glasgow Museum of Transport, Glasgow, Scotland,2007 to 2011, shown in figure (1.28).

Figure 1.28 Riverside Museum or the Glasgow Museum of Transport, Glasgow.
Source:www.glasgowarchitecture.co.uk/museum-of-transport-glasgow

- Vilnius Guggenheim Hermitage Museum, Vilnius, Lithuania, 2011, shown in figure (1.29).

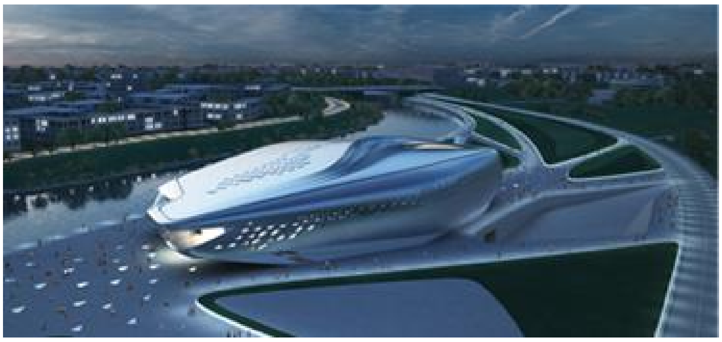


Figure 1.29 Vilnius Guggenheim Hermitage Museum, Vilnius.
Source: www.designbuild-network.com/projects/guggenheimvilnius/

New design techniques had taken their place over the past years in the architectural design. These techniques contained the computer design techniques, which helped the architects to form new definitions for the architecture of museums nowadays. The new design technologies were presented in few types including optimized, parametric, and algorithmic design as shown in figure (1.30).

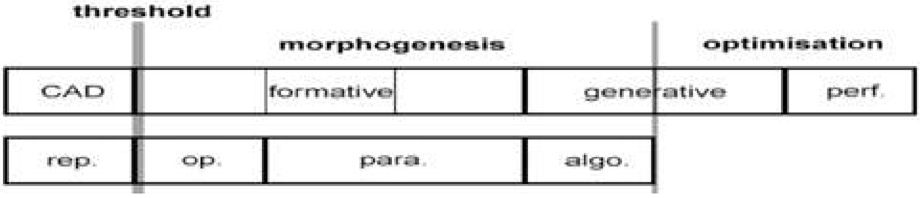


Figure (1.30) Towards a conceptual framework - comparison of Turing-based model with Oxman's classification.
Source: Kotnik, T.,"*Algorithmic Extension of Architecture*".

These two types depend mainly on some mathematical equations for generating the building form, connected to some variables controlling the end architectural product. Some examples of these technologies shown in the following examples:

- Chengdu Museum, Sichuan, China, designed by Sutherland Hussey Architects, 2007, shown in figure (1.31).

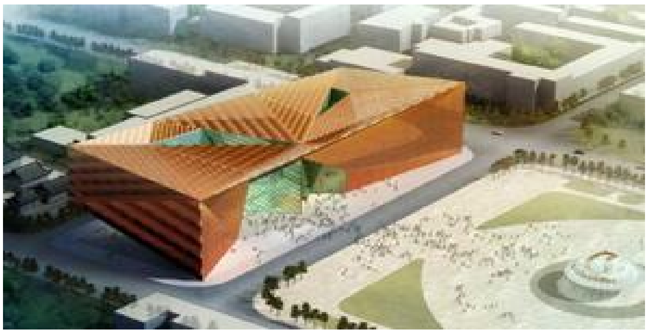


Figure 1.31 Chengdu Museum, Sichuan, China.
Source:www.e-architect.co.uk/china/chengdu_museum.htm

- Porsche Museum, Stuttgart, designed by Vienna's DeluganMeissl Associated Architects, 2011, shown in figure (1.32).

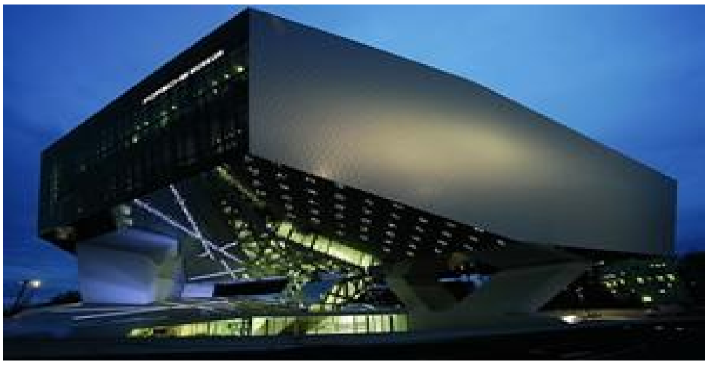


Figure 1.32 Porsche Museum, Stuttgart.
Source:www.porsche.com/international/aboutporsche/porschemuseum/theproject/architecture/

- Classical Museum on Saadiyat Island museum, Louvre Dubai, designed by Jean Nouvel, shown in figure (1.33).

Figure (1.33) Classical Museum on Saadiyat Island museum, Louvre Dubai.
Source:www.designbuild-network.com/projects/louvre-abu-dhabi/louvre-abu-dhabi4.html

- Dynamic museum, Dubai, designed by UN studio, 2008, shown in figure (1.34).

Figure (1.34) Dynamic museum, Dubai.**Source:**www.unstudio.com/projects/the-museum-of-middle-eastern-modern-art-momema

- Grand Egyptian Museum, Egypt, designed byHeneghan Peng's company from Ireland, using an algorithmic design by fractal algorithms, shown in figure (1.35).

Figure (1.35) Grand Egyptian museum, Egypt.
Source:www.hparc.com/work/the-grand-egyptian-museum/

1.4. The Role of Museums in the Society.

The museum roles in communities differ according to people's need; it depends on what is museum definition to them? Is it a source of information or a place for entertainment? Therefore, museums have many roles and it could be viewed as follows:

1.4.1. Cultural and Social Role[(1)].

According to the huge number of collections, which are presented in museums, museums became presenting an artistic and historic value, not only for country residences but also for the foreign visitors. Museums are keen on improving the artistic sense, spreading culture and knowledge, and scientific experience of the visitors, through the museum cultural message. This message is the main target that the museum designer focuses on, which has a deep effect on the visitor's experience, and consequently, the museum design. This message could be noticed in the arrangement of the exhibition hall, and the exhibition strategies. Through the visitor's tour inside the museum, the visitor has to get a special experience, develop intellect, takes advantage of the cultural entity, life philosophy in the past, and how it could be used in the present. Besides that, visitors learn about local civilization, and the pragmatic sense is raised.

1.4.2. Educational Role.

The museum educational role is considered one of the most important roles that museums do for the community. Scientists had identified museums as *"every institution presents any cultural properties for saving it and using it for educational purposes and spreading aesthetic pleasure…"*[(2)].

Museums are considered to be one of the places that it should be in direct contact with scientific institutions; in order to deliver a cultural and educational message. This connection importance was rectified and shown in some museums as:

- Alexandrian museum build by Ptolemy I ruling era between (323-305 B.C).
- Louver museum: La Ecole Du Louver (The Center of Teaching The History of Art), built at the end of the 19th century.

Museum institutions now are giving big importance for the educational part, which contains (e.g. lecture halls – show rooms – conference halls – Library). The educational part is now one of the basic functional requirements inside museums; which made architects of the 20th century extend museums outside their walls to achieve the concept of spreading its cultural and educational message to the community[(3)].

1.4.3. Touristic and Economic Role.

Because of political changes in the many countries, the public finance and museums finance are also affected after the fall of the private sectors. It became difficult to improve museums by buying new collections and expanding by building new museums. This problem was found in the

(1) زهدى، بشير، "المتاحف – دراسات ونصوص قديمة"، ص(72-76).
(2) Ibid, زهدى، بشير، ص77
(3) Ibid. P (649-651).

United Kingdom National museum of Arms and Armor during the establishing of the New Royal Armory Museum- opened in 1996 - and the Hermitage in ST. Petersburg, which was directed by an international expertise in finance to conduct major renewal work[(1)].So museum had to search for new source of finance, which became the entry fees. These fees became the main source of money used for museum development.

Museums are considered as a touristic attractor from inside and outside the country; because it gives a good idea about the country and its history in many fields (e.g. science, arts…etc.), which is between many things tourists need to know about the country. All of that makes the tourists need satisfaction one of the museum main roles[(2)]. With the increase of the museum income, it became easier to extend the museum collections and attract more visitors from many countries. For satisfying more visitors the museum became containing new entertainment spaces that make the museum visiting time a cultural and entertainment visit. The museum income will help increase the national income by attracting foreign tourist, and it is easy to do that especially for the countries have an old history and civilization[(3)].

1.5. Types of Museums.

Now museums became a beacon of science; it is mainly preserving all the humankind's achievements in many fields, including art works, invents, antiques and materials of different times from many places[(4)]. According to that, museum buildings could be classified to the following[(5)]:

1.5.1. According to the time of Manufacture.

This depends on the pieces time of manufacture:

- Ancient times(B.C)Museums, such as Egyptian Museum and Papyrus Collection, Berlin, shown in figure (1.36).

Figure 1.36 Egyptian Museum and Papyrus Collection, Berlin.
Source:www.egyptian-museum-berlin.com/c01.php

[(1)]Ibid, Lewiss, G.
[(2)]Ibid, زهدى، بشير، ص75-76
[(3)] Ibid,Abd El Rehem, M. M
[(4)]فيليب، آدامز وآخرون، "دليل تنظيم المتاحف- إرشادات عملية"، ص 11
[(5)]Ibid,عاصم، أيمن

- Medieval times Museums, such as Waterford Medieval Museum, Ireland, as shown in figure (1.37), and The Museum of Medieval Stockholm, Stockholm, as shown in figure (1.38).

Figure (1.37) Waterford Medieval Museum, Ireland.
Source:www.archdaily.com/487908/medieval-museum-in-waterford-rojo-studio-architects/

Figure (1.38) The Museum of Medieval Stockholm, Stockholm
Source:www.medieval.stockholm.se/museet.php?sprak=english

- Renaissance time Museums, such as The Museum of Modern Renaissance, USA.
- Modern ages Museums.
- Future Museum.

1.5.2. According to the Museum Size.

It is depending on knowing the museum size (Big – Medium – Small), according to:

- The Museum area that affects the no. of exhibition halls, its area, and museum facilities.
- Number of displayed and stored pieces.
- Numbers of visitors.
- The museum budget and income.

The differences between each museum are noticed in the no. of exhibition halls, and their size, in addition to exhibition techniques.

1.5.3. According to the Targeted Groups of Visitors.

The differences between visitor's groups are a result of many factors, including visitors' ages, countries, scientific backgrounds, and the visitor's nature. These types of museums could be classified into:

- Children's museums, such as The Children's museum in Manhattan &Boston [1].
- Disabled museums, such as The Museum of disability history, New York[2], as shown in figure (1.39).
- Specialized museums, such as The War museums, Literature museums and musical museum[3].

[1]www.childrensmuseums.org/index.php/professional-development.html
[2]museumofdisability.org/
[3]Ibid,111زهدى، بشير،ص

Figure 1.39 The Museum of disability history, New York.
Source:museumofdisability.org/information/about-us/

1.5.4. According to the Exhibition Technique.

This type of museums depends on choosing a style and shape for exhibiting collections. They might use the halls for displaying, or use some actors for telling the story that is called the living museum. Museums can also depend on the interaction between visitors and the exhibits, or using the virtual museum presentation.

1.5.5. According to the Targeted Visitor's Reactions.

The interaction between visitors, the exhibits, and the museum building itself can affect the museum design. The expected impressions could be fear, or inspiration, angry or exciting, such in the Japan Airlines Safety Promotion Centre, Tokyo.

1.5.6. According to the displayed branch of knowledge.

Museum classification according to the branch of knowledge started at the beginning of the 19th century. Museum typological classification could be divided mainly into four types of museums(1):

A. General or specialized museums.

This type of museum exhibits varied collections in many fields, therefore it was known as the multidisciplinary museums. Many of these museums started in the 18th, 19th and the beginning of the 20th century. It started by presenting the private collections and then varied collections beside its own collection(2).General or specialized museums are embodied in certain museums like Children's museums and the Regional museums beside the Open-air museums.

- Children's museums are mainly focusing on delivering cultural and educational information for children, and presented in a certain way to make it easy for a child to get the targeted information(3). Some of the most famous children's museums are(4):
  - The children's museum in Boston.
  - The children's museum in New York.
  - The national museum in New Delhi.

(1)Ibid. P.657.
(2)Lewiss, G, "*Types of museums*".
(3)Ibid,Abd El Rehem, M. M
(4) Ibid.

- Regional museums are connected to a certain region or a community, reflecting its heritage, regional culture, customs and traditions beside the encyclopedic spirit of this time. It exhibits different types of collections of art, history, science and other fields in order to give lots of information about the region civilization and open the community to the world[5].

Most of these general museums are working on knowledge spread. It is widespread in eastern and western in Europe, India, Australia, New- Zealand, and in the northern and southern Americas.

B. History museums[1].

Any museum presents its collection with a historical order or from a historical perspective is named as a "history museum". This type of museums helps in raising the cultural awareness of a certain country. Most of historical museum display the country history from its origin to present, or for a certain period of time and it is mainly for the time before the industrial revolution like:

- The Musee National des Arts ET Traditions Popularizes of Paris.
- The Museum of English Rural life of the University of Reading, Berkshire.

The collections are exhibited with a modern way in traditional fashioned buildings. Under the name of historical museums, many types of history could be found like:

- Museums of personal memorial.
- Museums of archaeological sites[2].
- Museums built on historical monuments.

From the most famous museums:

- The Egyptian museum – Saladin Citadel museum – Nubian museum, Egypt, shown in figures (1.40), (1.41) & (1.42).

Figure 1.40 The Egyptian museum, Cairo.

Source: www.sca-egypt.org/eng/MUS_Egyptian_Museum.htm

Figure 1.41 Salah El din Citadel, Cairo.

Source:www.cairocitadel.gov.eg/egypt_in_mohali_A.html

Figure 1.42 Nubian Museum, Aswan

Source:www.numibia.net/nubia/outdoor.htm

- National Museum, Beirut.
- National Archaeological Museum, Athens.
- The Historical Museum of Serbia, Belgrade.
- The Prado "Museo Nacional Del Prado", Madrid.

---

[1] Ibid,Abd El Rehem, M. M.
[2]Ibid.
[3]**Archaeology museums**: - those museums that concern mainly with historical recorded parts from the ground or pieces of information witnessed on an event held in a certain period.

- The Historic Royal Palaces, including the Tower of London.
- The Royal Ontario Museum, Toronto, Canada.

C. Natural history and science museums.

Natural history museums are those museums, which concern mainly with natural history and natural elements such as plants, animal, and human. The idea of natural history museum started with “Cabinet of Curiosities” in prince’s palaces during the Renaissance time in Europe such as:

- The Ashmolean Museum, Oxford.
- The National museum of natural history, Paris.
- British Museum, London.

During the 19thcentury, this type of museums developed and spread in many countries such as the USA and South America. The collections that were presented in these museums contained (pieces of social anthropology and natural history). Now Natural history museums are involved in scientific researches beside its main function. These scientific researches are mainly for observing natural factors, biological changes for some animals and plants, in collaboration with environmental organizations and institutions[(1)]. Between the famous Natural history museums:

- Natural history museum, London.
- Smithsonian institution natural museum of national history, Washington.
- American museum of natural history, New York, which is holding many specimens of the natural world.

Science museums are those museums concerning the development of science and technology. Those museums were designed for spreading the awareness of technological development; to make communities keep going with the new development in the field of science. Science museums appeared in the 18th century in London and Paris, and evolved in the 19th century and became widespread in many countries specially Europe and USA.

During the 20th century, they were known as Applied Museums, as the way of presenting their exhibits depending on live demonstration and the interaction between the visitors and the exhibits using physical experiments and real modeled objects[(2)]. Most of science museum visitors are for children and adults because the used way of presenting exhibits delivers the museum massage easily like:

- The Deutsche Museum, Munich.
- The science museum, London.

Biggest industrial companies are very interested in this type of museums; because they are using it for presenting their latest industrial researches and marketed product[(3)]. Many science museums constructed under the name of “Center of science and technology” nowadays such as:

- The new Ontario science center, Canada.
- Frederick Phineas and Sandra priest rose center for earth and space, New York.

[(1)]Ibid, Lewiss, G.
[(2)]Ibid,Abd El Rehem, M. M
[(3)]Ibid.

D. Art museums[1].

It was named "Art Galleries" in the time before the industrial revolution. Art museums are those museums, which exhibit pieces of a certain art and concerned with the aesthetic value. It contains many types of art between paintings, sculptures, folklore, music, decorative art and beside that the industrial art which was added to art museums in the 19th century. The main function of these museums appears in making the society more familiar with the arts and its evolution.

Art collections always need special environmental conditions (e.g. light – temperature – humidity) for exhibition and storage. It is preferable when displaying art collections to use an artificial light. In museums of antiques, it is preferable to use stands and showcases as a piece of art in themselves. We can find some industrial art collections presented beside the other collections. Art museums are playing a great role in tourism and spreading the cultural awareness.

As for modern art museums, it is different from other art museums; they are given up to art in the process of development and to the aesthetic environment of contemporary life. Art museums as:

- Grand Louver, Paris.
- Museum of modern art, New York city, figure (1.43).


Figure 1.43 Museum of modern art, New York.
Source:www.e-architect.co.uk/new-york/moma-new-york

- Pompidou Centre, Paris, figure (1.44).


Figure 1.44 Pompidou Centre from outside and inside, Paris.
Source: www.greatbuildings.com/cgi-bin/gbi.cgi/Centre_Pompidou.html/cid_2348201.html

(1)Ibid, Lewiss, G.

1.6. Conclusion

This chapter was mainly discussing the genesis of Museums; the word Museum was extracted from the word Muse, which means "The protector of arts", and the place for inspiration. In addition, the linguistically and scientifically definitions of the word Museum have been introduced.

Then, a brief history for the evolution of Museum building was reviewed, starting from the ancient times (B.C), passing through the Medieval times in Europe, the Renaissance period, the late 17th century, going through the 18th century, up to the 19th century, reaching the 20th century, and the 21st century with a traveling tour from place to another in the virtual museum, as shown in figure (1.45).

After that, more clarifications were introduced of the Museum Cultural, Social, Touristic, and Economic roles for the society through the Museum cultural message, which differ according to the museums typologies. Museums could be classified in accordance with its size, exhibition techniques, the type exhibited artifacts, and its time of manufacture, the targeted visitors, and the kind of knowledge the museum exhibiting. According to this classification, the Museums designs will differ, consequently the exhibition halls design, which highlights the relation between the museum cultural message, and the exhibition hall design in combined with the exhibition techniques that will be introduced in the next chapter.

Figure 1.45 Architectural evolutions of Museums.
Source: - Done by the researcher.

Chapter 2: Museum Exhibition Hall Design

2.1. Introduction.

As previously discussed, the conception of the museum building was at the end of the 18th century and the beginning of the 19th century. That made the museum building very similar to palaces as it was part of it. After museums became in a separate building, the concept on Museum building Architecture has risen. As the architecture is the art of designing a building for specific functions, the museum building became a piece of art designed and built upon an architectural program to host some managed exhibition, educational, and entertaining activities. The museum architect is the person who designs the envelope surrounding exhibits, visitor's and staff, and provide it with specific facilities including lighting systems. Some of the architects are involved in the exhibition process and became specialists in its techniques they were called Museographers. In the second half of the 20th century, some modification has taken place in the museum design, including increasing the spaces for temporary exhibition against the permanent exhibition, which lead to creating more spaces for storage and restoration labs. New functional spaces have been provided as visitor facilities, such as bookshops, restaurant, rest zones… etc. (1).

Nowadays, museums are one of the most important public buildings, as it gets the major concern of society members; due to its significant roles for communities good. Because of the diversity of knowledge branches between astronomy, biology, the history of humankind and others, many types of museums appeared all over the world.
The differences between museum visitors impose a new problem in the museum design. The design process of any building is very different from designing public buildings such as museums or galleries. This type of building design is mainly depending on three factors:

- Presented pieces and information.
- New ways of exhibition.
- Visitor's behavior.

2.2. Museums and Visitor's Experience.

After museums have become for the public, it became a need to study the interactions between the museum envelope and its visitors, which is called "Museum visitor's Experience". The definition was stated by John Falk and Lynn Dierking, as "the result of the interactions happened between three main contexts"(2), as shown in figure (2.1).

- **Physical context** (the museum architecture, atmosphere, and exhibited artifacts and the way they are displayed in).
- **Personal context** (visitor's life experience, interests, motivations, expectations, prior knowledge, experience, beliefs, choice, and control).
- **Social context** (depending on if the visitor is alone in his visit or with friends or family, or a member of a group).

(1) Desvallées.A and Mairesse. F,"*Key Concepts of Museology*".
(2) From:
- Falk.J and Dierking. L., "*The Museum Experience*".
- Henery, C. "*How Visitors Relate to Museum Experience: An Analysis of Positive and Negative Reactions*".
- Smit. R. MA, "*Rethinking Museums from a Visitor's Perspective*".

Each of these contexts has a recognizable effect on the visitor's experience, especially the personal context that makes it different from a visitor to another, which should be considered from the museum curators and studied from the visitor's perspective. Another approach was introduced by Mihaly Csikszentmihalyia and Rick Robinson, explain that the aesthetic experience is the museum ultimate experience(1).

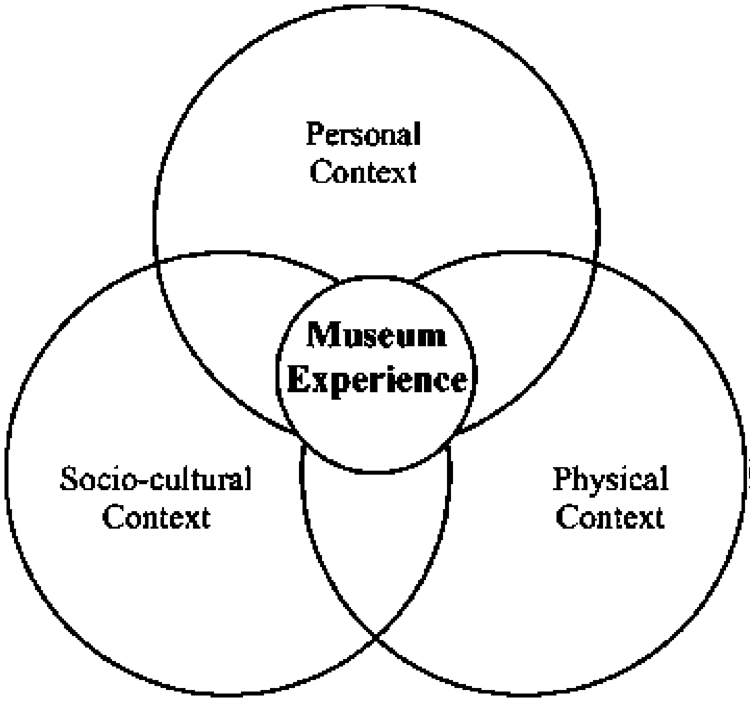


Figure 2.1 Museum Visitor's Experience.
Source: Falk.J and Dierking. L., "*The Museum Experience*".

According to that, and as the architecture of a museum is about creating, designing, and installing a space that will be used to display specific exhibits for public interest.In order to design a museum, the designer should study these main contexts as follows:

Physical context

Through studying the following:

- The design of museum spaces, especially exhibition hall design.
- Artifacts exhibition strategies, techniques, and approaches.
- Visual directionality.

Personal and Social contexts

Through studying the following:

- Visitor's characteristic.
- Visitor's movement.
- Visitor's behavior.
- Visitor's traffic flow.

(1)Ibid, Henery, C.

2.3. Planning a Museum.

Museums are a distinctive type of buildings, because it is considered as an artwork in itself. The architectural design of the museums is one of the most important challenges facing the architect, as it is not enough for him to achieve the main function of the museum but also creating a new landmark for its area. There are some parameters affecting the establishment of any museum, including[(1)]:

- The purpose for establishing a museum.
- Identifying the targeted groups of visitors.
- The proposed site for museum.
- Types of collections and its exhibition ways.

During the last three decades, the site selection of museums regulations states that the museum site must be inside towns for some reasons related to the town urban design and others are political[(2)]. Consequently, new routes of transportation were established to serve museum visitors and new educational institutions were placed closer to the museum area. These days this ideology changed and the site selection of new museums became outside the towns, away from the overcrowding in lands with cheaper prices than inside the town. The new lands in the desert allow museums to extend beyond its borders, and provide it with a green belt protecting the museum building from dust and corrosion. The Grand Egyptian Museum is an existing example for this conceptual orientation, while the museum site still sticks to the above-mentioned parameters.

Museums are different from each other in some functional requirements, and there are some required elements common, especially in the pre-design stage. In the beginning of the design stage, the architect has to verify the main functional requirements followed by determining the functional relationships between every type of spaces in the form of zoning, and then the functional space program taking into consideration the museum size and the type of exhibits.

2.3.1. Museum Zoning.

Every building has its main zones, and every zone contains some Major and Minor spaces that participate with each other's in the same function. Major spaces are those spaces should be found in all types of museums, especially in small museums, which include (Entrance hall - Main exhibition hall for permanent exhibition - Administration and service spaces - Storage spaces). As for Minor spaces; those are spaces which could be found especially in big museums, that includes spaces like (Small exhibition halls for temporary exhibition – Library – Lecture and study halls – Computer hall and showrooms – Preservation and restoration laboratories – Public services). Every space connected to the other spaces in the cluster with some ways. Therefore, the next stage of designing a museum is to get the relations connecting between the major spaces and the minor spaces, by making a zoning diagram to put these spaces in an order according to the importance of each space, the type of movement inside different spaces, and the connection to the main circulation routes inside the museum.

(1) خلوصي ، محمد ماجد، أحمد أيمن, "الموسوعة المعمارية – المتاحف – الجزء الأول"، ص16-17

(2) Chiara, J, Callender, J, "*Time-Saver standards for building types*", P (365).

The museum building is divided into the following zones[1] and as shown in figures (2.2) & (2.3):

- **Zone A – Public zone.**
  It contains spaces customized for the visitor; which includes (Main entrance – Main exhibition halls – Temporary exhibition halls – Entertainment area – Library – Conference halls – Computer labs – Gifts shops).
- **Zone B – Administrative zone.**
  It is the area for museum administration staff and workers; which is must be directly connected to zone A and zone C, for a complete supervision on all the museum contents and activities. It is mainly consists of (Museum Manger's room – museum staff & guide's rooms – security room).
- **Zone C – Services zone of exhibition.**
  It is the exhibition service spaces such as (Exhibition storage – Restoration labs – Service route).

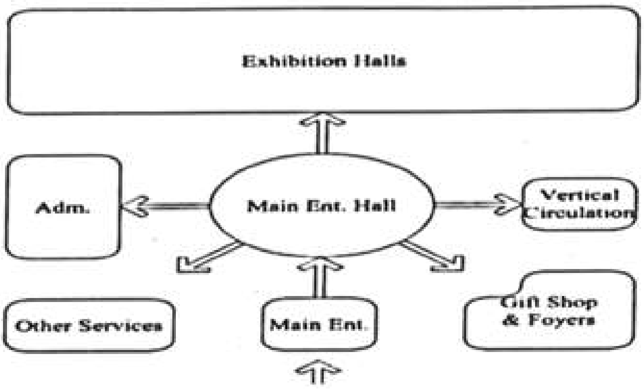


Figure 2.2 Main zones of museum building.
Source: Abd El Rehem, M. M, "*Museums and Architecture*"

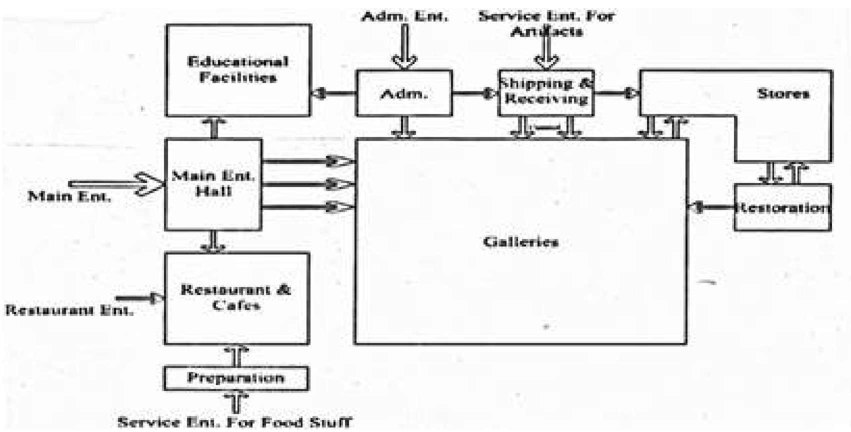


Figure 2.3 The relations between each zone inside museum building.
Source: Abd El Rehem, M. M, "*Museums and Architecture*"

After deciding the main spaces to be implemented in the museum design, the museum entrance and connections between the three zones, in addition to the main spaces for exhibits presentation and storage should be taken into consideration before starting to design each zone separately as follows:

[1] Ibid, Lord G, D and Lord B, p (283 – 288).

2.3.2. Museum Entrances.

Museums contain three types of entrances, which could be found in big museums, and it could be just two entrances in case of small museums, explained as follows:

A. Main entrance [(1)].

This entrance is particularly for museum visitors. It is the most important entrance in the museum; it gives visitors the first impression about the museum. All museum contents could be recognized through the entrance hall. Main entrance should be placed on the most important elevation of the museum, to be more attractive for people and easy to reach. The main entrance is directly connected to the entrance hall and from it to the main circulation routs. The museum designer depends mainly on the entrance hall to open new ways for movement inside the museum in many directions, so the visitor can start his trip from the place he wants according to his personal interest. The main entrance usually containing:

- Information desk.
- Ticket sale office.
- Security desk.
- A connection to visitor's service.

B. Staff entrance [(2)].

This entrance is particularly for museum staff. It could be found just in large museums, because in small museum staff could enter the museum through the Main entrance with visitors or through the service entrance. This type of entrances could be located on any of museum elevations, on condition it leads directly to the administration zone that is close to storage zones and exhibition halls.

C. Service entrance [(3)].

It is one of the main entrances in the museum, because it is the entrance for exhibitions and leads to the storage areas, restoration laboratories, and to exhibition halls. Service entrance should be placed away from the main entrance and near Service Street to facilitate the transformation of exhibit pieces by trunks or vehicles to museum storages.

2.3.3. Museum Circulation routes.

Movement circulation is an important factor to be studied carefully for any public building people can go through it freely. Museum building has two types of movement inside it; one for visitor's movement and the other for exhibits. Those two types should separate from each other for keeping the exhibits safe. It could be explained as follows:

A. Exhibits service routes.

Exhibit circulation is starting from the service entrance going into the storage area or to the restoration area through a corridor. After deciding its suitable place inside one of the exhibition halls it transferred to it through another corridor[(4)]. Those routes should be with minimum dimensions of 2m width with 2.75m ceiling height and provided at its end with a door 1.8m width and 2.6m height.

[(1)]Ibid, Chiara. J, Callender. J,P (334).

[(2)]Ibid,Abd El Rehem, M. M.

[(3)] Lord G, D and Lord B, "*The Manual of Museum Planning*", Grown copy right, HMSO for publication, London, 1991, P. (115-116).

[(4)]Ibid, Chiara. J, Callender. J, P (375).

B. Public service routes.

The connecting routes between exhibition halls and most of the public spaces inside the museum with a width and height could be determined according to the movement capacity between halls. In addition to that, another route for entertainment spaces (e.g. restaurants, cafes, gift shops…etc.) need also a circulation route for its service. It is for delivering food and things like that and it should be connected to the service entrance and directly connected by another corridor to its food storages and kitchens, this service route should not be less than 1.2m width with 2.4m height and provided with a door 1.8m width with 2.6m height at its end [(1)].

2.3. Exhibition Hall design.

Exhibition halls are the main core of any museum. It could be divided into two types (Main exhibition hall – Temporary exhibition hall). The Main exhibition hall is used for permanent exhibition; this hall mainly contains the biggest or the most important pieces in the museum. Temporary exhibition halls are considered as minor spaces inside the museum because its presence depends on the museum size. Exhibition hall dimensions are defined according to the type and size of exhibits, and the type of museum. Main exhibition hall most common dimensions are (7-8 m) wide, (21-27m) long, and (4-6 m) high[(2)].

2.4.1. Exhibition halls cluster.

Exhibition halls are collected with each others to create what so – called the cluster form. Cluster form is a metaphor for the arrangement of exhibition halls, this arrangement is affected by the visitor's way of movement inside it every hall. The exhibition hall cluster could be changed due to two main factors (Museum size and type – Exhibition hall arrangement), so the exhibition halls clusters could be classified according to the ways of arrangement as follows[(3)]:

A. Linear cluster.

Exhibition halls are following each others on one liner row. The entrance will be at the first hall and exit at the last one, as shown in figure (2. 4). This type of cluster could be used in the historic museums which depends on the historical sequence for presenting exhibits, so the visitors will be able to see most of exhibited pieces. As there is one entrance and the exit is the entrance to the next hall it makes the museum more secured, but sometimes it makes many visitors be in a hurry to finish the tour in order to find the exit door and get out of this attached hall, or from the museum. In the case of putting the entrance and the exit on two opposite walls it will cause a telescopic view so it is preferred to be with non-followed entrance and exit, but it makes the visitors move in two different directions inside the hall.

[(1)]Ibid, Abd El Rehem, M. M.
[(2)]Ibid, Abd El Rehem, M. M.
[(3)]Ibid,صلاح الدين، خالد

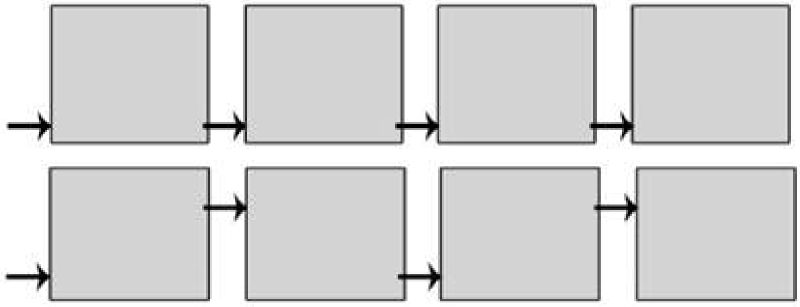


Figure 2.4 Linear cluster with followed and non-followed entrances and exits.
Source: - صلاح الدين، خالد، "عمارة المتاحف"

B. Loop cluster (semi – circular).

Exhibition halls are arranged in the form of semi – circular shape with a court in the center as shown in figure (2.5). This order of halls allows the visitor to go in one direction, but having the choice to get out of this sequence and go back at any time. This type of cluster could work with many types of museum small and medium museums, but not with large museums as it takes a huge space from the museum land

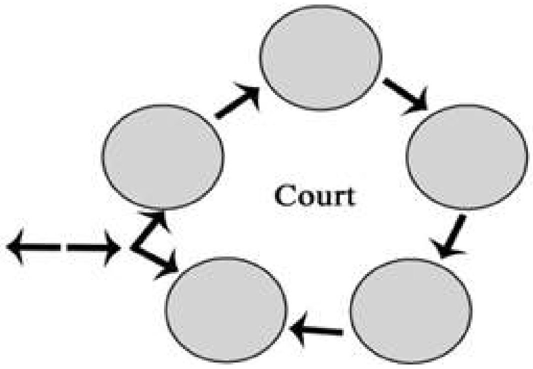


Figure 2.5 Loop cluster (semi – circular).
Source: - صلاح الدين، خالد، "عمارة المتاحف"

C. Cored cluster.

Exhibition halls are arranged in the main hall at the core and other smaller halls around the core as shown in figure (2.6). This type of clustering provides more free movement for the museum visitors to get out the halls very soon as it is not depending on a rigid sequence of presenting pieces and they are differing from a hall to another. The main hall is the most important hall as it contains the biggest number of pieces. This type of clustering is not preferred to be used from the visitor's point of view.

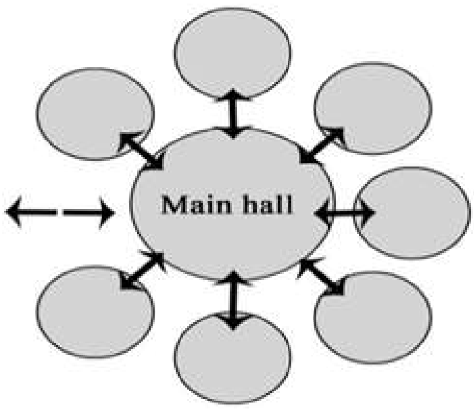


Figure 2.6 Cored cluster.
Source: - صلاح الدين، خالد، "عمارة المتاحف"

D. Organic cluster.

This type of clustering follows the human nature and provide the visitor with the free well to choose his way as he wish, so he can cut the tour and go in the time he want without visiting all halls, as shown in figure (2.7). This type of clustering is not preferable; as it will cause a lot of disturbance for the other visitor's movement and make it hard to reach all halls inside the museum. As a result of that, this type is not used in most of the museum except in the small museum.

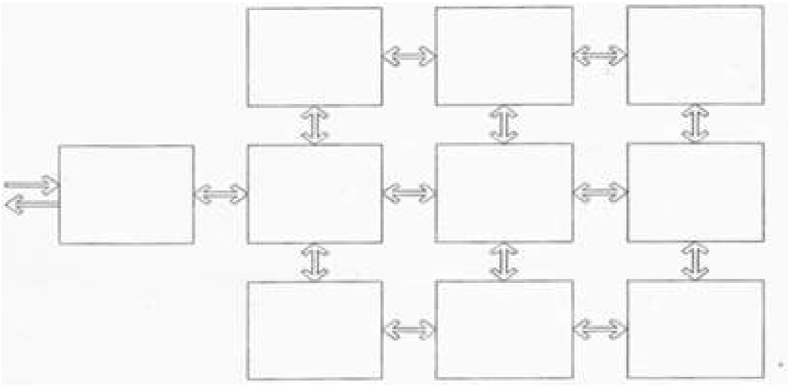


Figure 2.7 Organic cluster.
Source: Abd El Rehem, M. M, "*Museums and Architecture*"

E. Complex cluster.

It is mixing between the previously explained clusters as shown in figure (2.8). It could be used in big museums and for museums which presents many types of exhibitions.

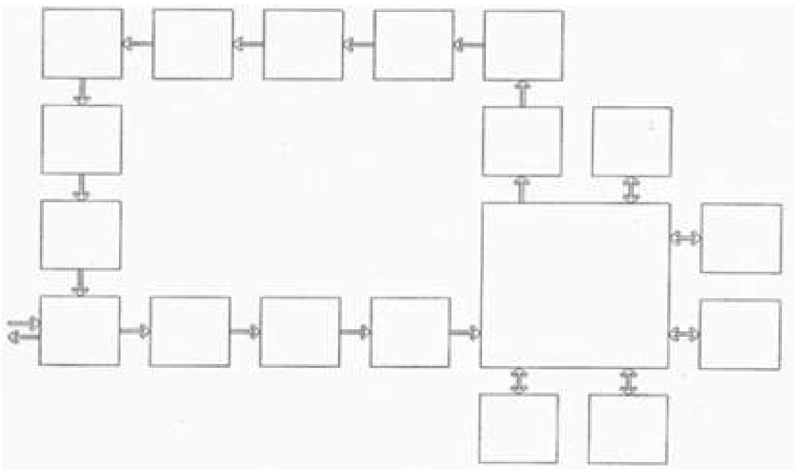


Figure 2.8 Complex cluster.
Source: - Abd El Rehem, M. M, "*Museums and Architecture*".

2.4.2. Exhibition process and Display strategies.

The exhibition is not only about how to display artifacts; it should be combined with an interpretation. Exhibits should be combined under two important principles, which are Aesthetic and Entertaining. Museum visit is a trip, aims to make the visitor live an unforgettable entertaining experience. This experience could motivate the visitors to come many times, which definitely will help museums to increase its income. In this step, the exhibit designer has to go about planning the exhibit layout by studying all exhibits in depth, in order to arrange them in an aesthetic, educational, logical, and entertaining way and help visitors to view exhibits in a certain sequence(1). The visitors have to get a particular result from what is presented to them.

A. Exhibits arrangement.

In order to make an exhibition plan; some steps should be followed, fist the sited goal to be achieved from this exhibition should be known, then the way to reach this goal is steps, after that where to place each exhibit in the plan to reach this goal. There are some factors affecting the exhibition spaces design should be taken into consideration(2):

1. Size and type of exhibitions.
2. The number of exhibited pieces.
3. New exhibition techniques.
4. Number of visitors expected during the day and in the peak hours and their behavior.

There are two types of exhibits the designer should deal carefully with them, and arrange them in a charming way, according to its importance, and the following table (2.1) shows a comparison between those types of objects.

Table 2.1 Exhibited object types (3).

Comparison	2D Objects	3D Objects
Definition	Or flat objects, it could be defined as the objects with a small thickness and could be seen in X & Y plan.	Or objects with a length, width and a visual depth, and have protrusions in all directions
Arrangement	These objects are fixed to wall, or to a plain surface, or on the ground.	3d objects are presented in a bigger free space, as it is one of the factors affecting the visitor's movement.
Examples	Paintings, prints, drawings, posters & textiles.	Sculptures, temples 3d models & mummified animals and other living creatures.
Display	Cases, plinths, and vitrines.	Freestanding cases (up to 5m in height and 15-20m in length).

(1)G.EllisBuracw, "*Introduction to Museum work*",P(133).
(2)Ibid, Abd El Rehem, M. M.
(3) Dean. D, "Museum Exhibition - Theory and Practice", P (55 - 56).

B. Exhibition techniques and approaches.

As the exhibition techniques are one of the factors which affect the museum success; so the designer has to deal carefully with it and usually searching for the new techniques emphasizing the exhibits value, as it should be presented in a rational order. In the beginning of the 20th century the aesthetic presentation was dominating on most of museums around the world. After 1950, new techniques have been introduced. Consequently, the presentation techniques and approaches changed as shown in table (2.2).

Table 2.2 Exhibition techniques and approaches(1).

Approaches	Techniques
• **Open storage approach.** **It is depending on putting the exhibits, as it is required, without organization or previous selection for exhibition. Same objects in size, same donor, or period, are presented together.**	• **Aesthetic presentation.** It is only applied in art museums for presenting art collections (e.g. paintings, portraits, sculptures…etc). Every piece from the collection presented separately or collected in an aesthetic way.
• **Object approach.** **In this approach, exhibits are selected from the collection and arranged to produce an educational exhibition.**	• **Historical presentation.** It is usually applied in museums of history, archaeology, antropology & ethology. The presentation method depends on heritage revitalization by arranging pieces in historical sequence, or in the form of telling a story using the exhibited pieces.
• **Idea approach.** **This approach is concerned with the educational role of the museum, so a story will be presented using selected exhibits from the collection. It is depending on presenting each exhibit as separately not in a group of exhibits.**	• **Ecological presentation.** It is applied in science & technology museums and in natural science museums. The presentation method depends on creating a diorama (the real environment) for the presented organisms as in Natural History Museums, and the interaction between visitors and the Inventions in technological museums.
• **Combined approach.** **In this approach, just significant exhibits and ideas are selected, in order to deliver the museum message.**	

Because of the new technology taken place in the recent decades, new exhibition techniques have been introduced, using computer software and touching screens as exhibits. This concept is applied in the KAUST Museum of science and technology in Islam, KSA, shown in figure (2.9), in this museum, most of the exhibits are touching screens connected to a powerful computers with displaying software, contain all the needed data to be shown, so the visitors can select the field he is interested in by his fingers from the list on the screen, and the screen display it.

(1) From:
- Ibid, H.H, B.C, P (653).
- Ibid, G.EllisBuracw, P (133-136).

Figure 2.9KAUST Museum of science and technology in Islam, KSA
Source: museum.kaust.edu.sa/

C. Visual directionality.

At the hall entrance, visitors should be attracted directly to the main or the most important piece in the hall then the rest of the exhibits. Visual directionality is mainly the way the visitor could see the exhibited pieces in a certain order. It helps the visitor to decide his/her way through the hall by attracting the visitor to see it and move to the next objects, without leaving them unseen. It is mainly depending on the object weight:

Light color → light object   dark colors → heavy object.

In the case of putting some paintings on a wall its location, ordering and orientation should be defined according to its location to the horizontal line and the viewpoint (or eye level). The viewer's eye should be spiralled between paintings in the composition. After that, the composition should lead the visitor to another one by using a spiraling pattern for visitor's eye, as shown in figure (2.10). Another way could be used for 2D and 3D objects called flanking. Flanking is a way for presenting the two types of exhibits, putting the largest object in the middle, and distribute the other exhibits in a symmetric way along the horizon line; so the visitor's eye will be directed to the center(1), as shown in figure (2.11).

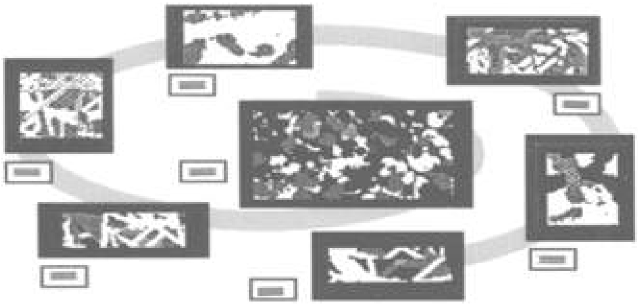


Figure 2.10 Spiraling way for presentation.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*", P (63).

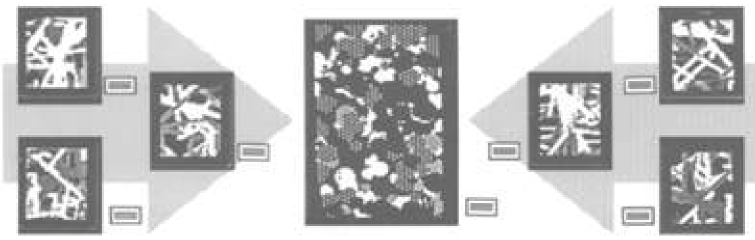


Figure 2.11 Flanking way for presentation.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*",P (62).

(1)Ibid, Dean. D, P (56 - 63).

2.4. The Museum Visitors.

2.5.1. Visitor's characteristics.

Museum visitors are vary due to some differences related to their ages, sex, size, education, religion, talents, and values, which make their interests and attitudes are different as well. As the main purpose of the museum is to serve visitors in many ways[(1)]; so their movement is considered the main circulation pattern for movement inside the museum, because it is the main path the visitors walk during the visit. Most of the visitor's movement is concentrated inside the exhibition halls; therefore, the visitor's movement pattern inside halls should be studied without any intersections with the exhibition pattern to achieve the most benefit of the visit, as shown in figure (2.12).

Figure 2.12 The visitor circulation inside MOMA Museum of modern art, New York.
Source: - Lundholm Associates Architects "*Art gallery of Saskatchewan – Functional program*", P (3-2).

The designer has to choose a suitable way to arrange exhibited collections to allow visitors to see most of these collections along the visit. Therefore, the designer has to study the human factor (people's movement and their attitude) inside this kind of spaces, and study the exhibition theories to make it easy for him to choose what would be the best way to present these collections according to its nature, the type of the museum, and the targeted group of visitors.

People differ from each other in some physical characteristics (e.g. weight, height, body features …etc.) according to age and gender[(2)]. The difference between man and woman in height in young adulthood could reach 1%, and the difference in height between 5 years old children and 20 years old adults in the range of 162%. According to these differences in age and gender, the average dimensions for most of the people and the basic dimensions for adults is shown in figures (2.13) & (2.14). These human dimensions allow designing a free movement, circulation route for visitors inside the exhibition halls with respect to *"The larger the space, the smaller the individual appears by contrast. Being lost in a vast space carries the emotional sensation of being less able to control the environment"*[(3)].

[(1)]Ibid, Dean. D, P(19).
[(2)]Ibid, Dean. D, P(39).
[(3)]Ibid, Dean. D, P (42).

Criteria	Female	Male	Child at age 8
standing height	64.5 inches (163.8cm)	70 inches (177.8cm)	51 inches (129.5cm)
eye-level standing	60 inches (152.4cm)	66 inches (167.6cm)	48 inches (121.9cm)
shoulder width	20 inches (50.8cm)	20 inches (50.8cm)	12 inches (30.5cm)
arms extended forward	33 inches (83.8cm)	36 inches (91.4cm)	25.5 inches (64.8cm)
arms extended upward	80.5 inches (204.5cm)	89.5 inches (227.3cm)	63 inches (160cm)
arms extended to sides	66 inches (167.5cm)	72 inches (182.9cm)	60 inches (152.4cm)
turning radius	48 inches (121.9cm)	48 inches (121.9cm)	36 inches (91.4cm)
seat height	15 inches (38.1cm)	18 inches (45.7cm)	13 inches (33cm)
wheelchair width	25 inches (63.5cm)	25 inches (63.5cm)	25 inches (63.5cm)
wheelchair length	42.5 inches (108cm)	42.5 inches (108cm)	42.5 inches (108cm)
eye-level from wheelchair	44 inches (111.8cm)	49 inches (124.5cm)	36 inches (91.4cm)

Figure 2.13 The average dimensions for most of people.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*", P (41).

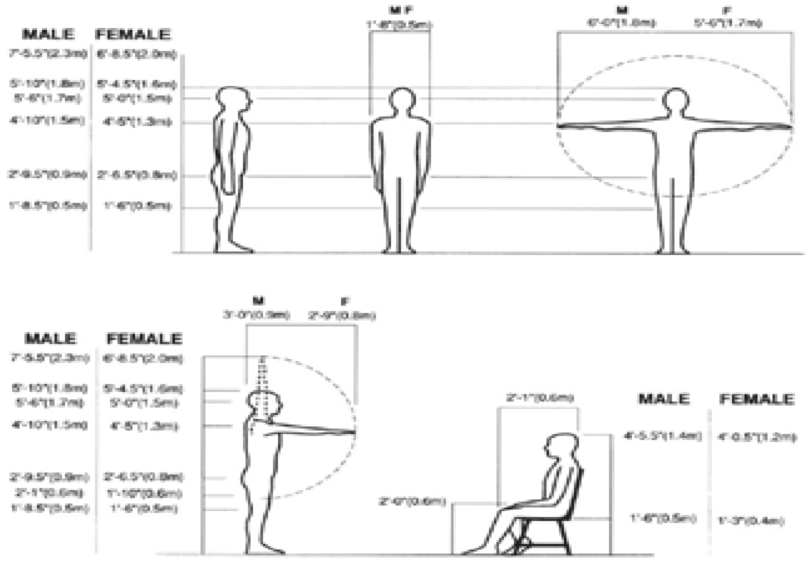


Figure 2.14 The basic dimensions for adults.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*", P (42).

The viewing heights and viewing distances for most of exhibits should be studied as the viewing height for adults in the range between (1.25m – 1.6m), and the vision cone for it is between (30° to 40°) above and under the view height level[(1)], as shown in figure (2.15).

[(1)] From :
- Ibid, Dean. D,P (43).
- Ibid, Chiara. J, Callender. J, P (339).

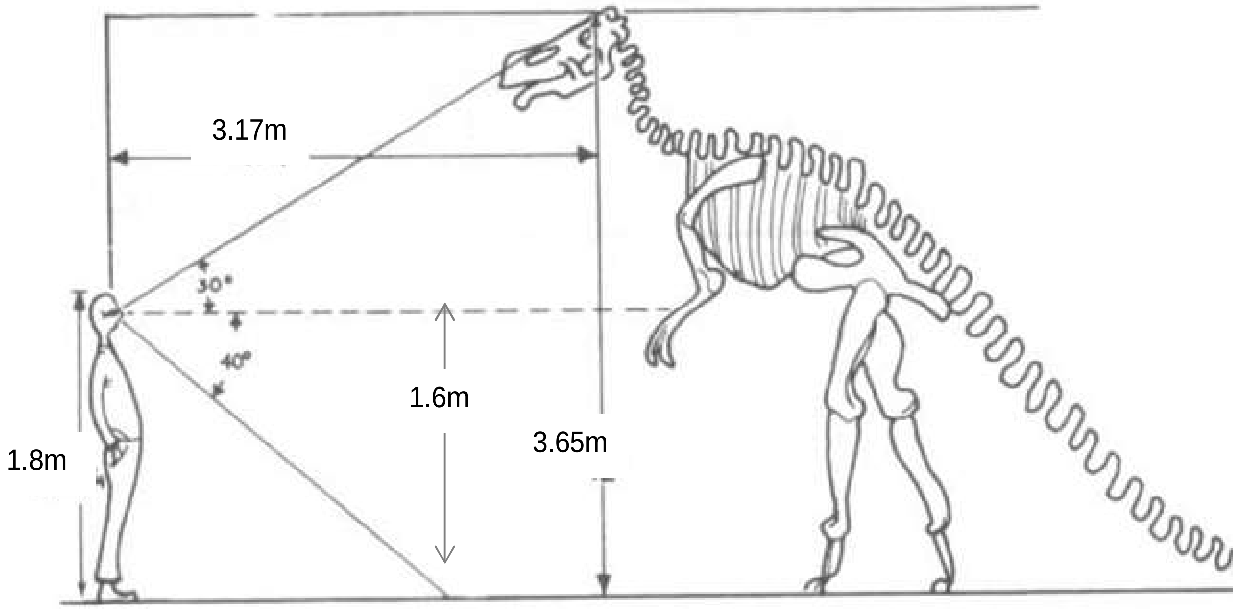


Figure 2.15 The cone of vision.
Source: - Chiara, J, Callender, J, "*Time-Saver standards for building types*" P (339).

During the visit a group of visitors can stop for a moment to get more information or studying something about one of the exhibits, therefore a suitable free space around exhibits should be taken into consideration to allow the visitors stop and study without making any disturbance for other visitors. A comfort seats or resting spaces should be added for big halls, to serve people who feel tired during the visit, and to avoid leaning on glass boxes or steps for exhibits(1), as shown in figures (2.16) & (2.17).

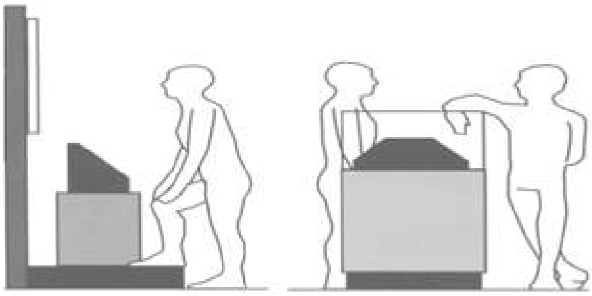


Figure 2.16 Leaning on exhibition box or stop for studying.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*", P (47).

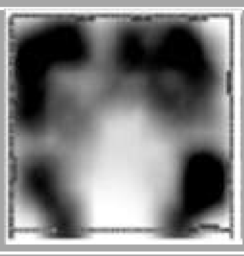
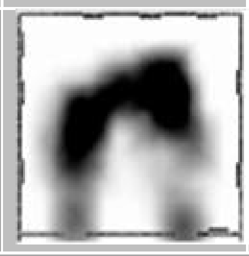
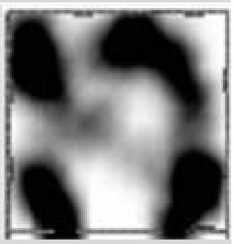
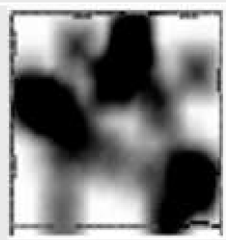
Figure 2.17 Seats for visitors in big exhibition halls.
Source: - Dean. D, "Museum Exhibition - Theory and Practice", P (48).

(1)Ibid, Dean. D, P (46 – 48).

2.5.2. Visitor's movement styles[1].

Due to the importance of museums and similar public buildings and the huge number of visitors every day; their visitor's movement and behavior in the built environment became an indication of their interest in the exhibited objects. According to the concept proposed by Veron & Levasseur; visitor's movement styles could be classified into four stereotypes (Ant visitor – Butterfly visitor – Fish visitor – Grasshopper visitor), as explained in Table (2.3).

Table 2.3 Visitor's behavior stereotypes[2].

Stereotypes	Ant Visitor	Fish Visitor	Butterfly Visitor	Grasshopper Visitor
Characteristics , Attitude & Speed	- This type of visitors is a curious visitor, pays attention to details. - Spend a quite long time to observe all exhibits. - Walking closer to exhibits and avoid empty spaces. - Follow a specific path.	- This type of visitors spends enough time to observe all exhibits. - Prefer to move and stop in the empty spaces at the center of the hall and avoid areas near the exhibits.	- This type of visitors observes most of the exhibits and ignores the rest. - Refuses to follow the proposed path and guided by a physical orientation.	- This type of visitors spends a long time to observe pre-selected exhibits and ignores the rest. - Finds his own path. - Prefer to stand closer to few exhibits that get his interest.
Selective exhibits randomness (no. of stops)	No selective randomness	No selective randomness	No - Random selection	Random selection
Preference weight randomness (viewing time)	No preference weight	No preference weight	Generate a less number of stopovers.	Generate a large number of stopovers.
Muse-graphic typology				
	Visitor location in Black color and their circulation in Gray color.			

[1] From:-
- Mancas. M, Glowinski. D and others, "*Hypersocial Museum: Addressing The Social Interaction Challenge With Museum Scenarios And Attention-Based Approaches*".
- Sookhanaphibarn.K &Thawonmas. R, "*A Movement Data Analysis and Synthesis Tool for Museum Visitors' Behaviors*", P (145 – 151).
- Antoniou.A &Lepouras. G, "*Adaptation to Visitors' Visiting and Cognitive Style*", P (1-2).
- Oppermann, R., &Specht, M, "*A Context- sensitive Nomadic Information System as an Exhibition Guide*".

[2]Ibid, Sookhanaphibarn.K &Thawonmas. R.P (145 – 151).

2.5.3. Visitor’s behavior.

The human behavioral tendencies are the most effective factor in the interior design of exhibition halls. According to the natural and the unpredictability of people movement, some behaviors are common among many people that could be discussed as in table (2.4).

Table 2.4 Human behavioral tendencies[1].

Behavior	Explanation	Design strategies
Turning to the right	Most of people prefer turning to the right direction, which could be according to the dominance of using the right hand.	Forcing the visitors to go through a certain route using barriers, or using a big, bright opening to attract visitors to go through it.
Following the right wall	Due to the turning to right action; most of people will focus on the right hand row of exhibits and left the others on the left hand row away from their target.	
Stopping at the first exhibit on the right side	The first piece on the right will have most of the visitor’s concerns and vice versa for the first piece on the left.	Using landmark exhibits distributed inside halls leading visitors along their drawn path through the halls.
Stopping at the first exhibit rather than the last	People’s interest and focus usually concentrated on the first piece, so they may lose their attention before they reach the end; as this piece located near the visible and nearest exit.	
Preference for visible exits	Entering an area without viewing its exit may cause some troubles for those who have some problems with closed and crowded spaces.	Make the exits visible for visitors by colors, lights or by using illuminated signs.
Reading from left to right and from top to bottom	<u>Western culture:</u> Reading a text is from left to right and from top to bottom. <u>Eastern culture:</u> Reading a text is from right to left and from top to bottom. The previous rules don't apply to the Asian languages.	Use a common way of expressing the text paragraph. Provide the pieces with paragraph text in the language and the way of reading of the country the museum located on its lands and another for the first languages all over the world.
Larger types more readable	Using bold and larger text for expressing information about the exhibits is more attractive than using smaller text with more technical details may make the visitor get bored quickly.	Using a larger and bold text, headlines followed by light text paragraph explaining the basic information about the exhibited pieces.

[1]Ibid, Dean. D, P (51-53).

Shortest route preference	Exhibitions placed on the shortest route are more inviting for visitors.	Using curved and diagonal routes, as these types of lines could be defined by the human's eye, which make the visitors see all the exhibited pieces in the hall.
Preference for right angles and 45° angles	Western culture: They prefer distributing exhibits on the hall corners with an angle between (45°– 90°) and left the center for free movement. Eastern culture: They prefer to focus on the hall center than corners.	It depends mainly on the type of presenting artifacts.
Aversion to darkness	As the humans are a daylight creature, human's eye cannot define shapes in the darkness beside that most of people fear of the unknown; consequently, visitors will avoid the darkest places and go to the shining places.	Using pools of light and attracting colors for different exhibition halls.
Chroma-philic& Photo-philic behavior	Bright colors and shinning places attracting most of people's eyes.	
Mega-philic behavior	Large objects attracting most of people entering their space.	Distribute large pieces along the visitor's route.
Exhibit fatigue	Because of the mental and physical effort visitors do during their visit they might suffer the exhibit fatigue.	A small transitional space could be attached to the exhibition halls, with different colors, lighting levels and ceiling height. The sudden change in space properties will make the visitors more curious about what they will see in the next hall and recharge their minds again. It could also be provided with an exit to the entertainment area, or some resting spaces.
30 min limit	30 minutes are the maximum average for adult's attention.	

2.5.4. Visitor’s traffic flow.

Under the study of human factor and how it can affect the exhibition design, the designer has to study the human traffic flow between exhibits after studying the human behavior and how it could be controlled. The human traffic flow will depend on first visitor’s worldview[(1)], second the way the exhibits are distributed inside the halls, and its educational characteristics. The used approaches are various but it depends on what the designer prefers according to the type of exhibitions and the purpose of establishing the museum[(2)]. In the following some approaches to control the visitors traffic, their advantages and disadvantages shown in table (2.5).

Table 2.5 Human traffic flow approaches[(3)].

Approaches	Description	Advantages	Disadvantages
Visual approach	It depends on attracting the visitor’s eye to draw his route inside the halls without any physical intervention. Some methods like changing in colors, light level, landmark exhibition, big texts and headlinesand wayfinding maps could lead the visitor along his visit through the museum halls.	• It gives the visitor the freewell to choose the designer’s suggested way. • It is a successful way for the delivering educational information.	• It depends on the designer’s imagination.
Free approach	The visitor is free to move and direct himself, according to his priorities. It is one of the space properties.	• It depends on the visitor’s the freewell to choose his own way	• This approach couldn’t be used in the museums which present its exhibits in a historical order or with a storyline presentation.
Addressed or Directed approach	This approach is a rigid and inflexible one. It forces the visitor to move in a previously defined way with a small ability to get out of the route without seeing all the exhibits.	• It is a good structured system and good way to control people’s movement.	• Many visitors will search for an exit through their path more than viewing the exhibitions. • In case one of the visitors decided to stop to get more information about one of the exhibited pieces it will lead to the bottleneck problem in the traffic flow.

(1)**Visitor’s worldview**: - means how the person sees himself, and how can he view the reality. It is affected by (culture, religion, psychology, physiology, esthetic background, & socio-economic status).
(2)Ibid, Dean. D, P (53 – 55).
(3) Ibid.

In the following some sketches expressing an example for the pervious approaches in figures (2.18), (2.19) & (2.20).

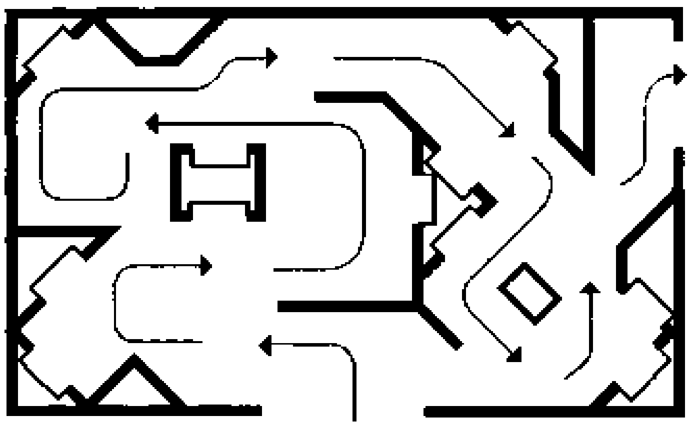


Figure 2.18 Human traffic flows – Visual approach.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*",P (54).

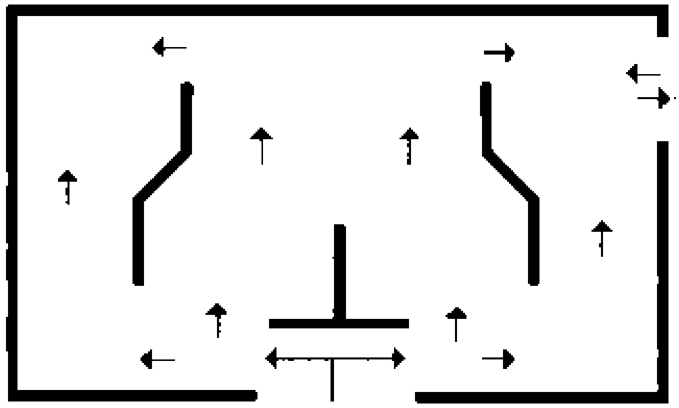


Figure 2.19 Human traffic flows – Free approach.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*", P (54).

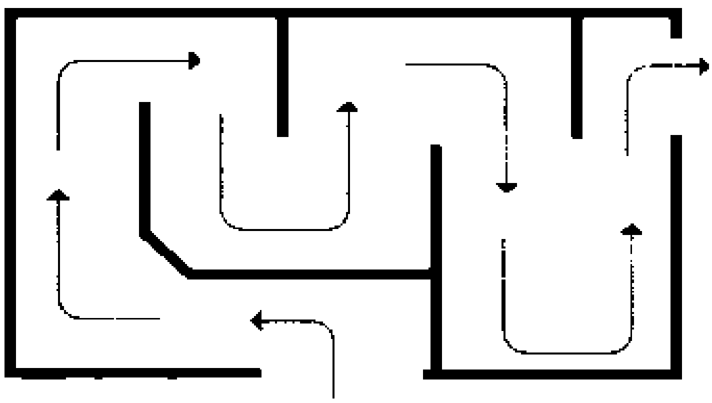


Figure 2.20 Human traffic flows – Addressed or Directed approach.
Source: - Dean. D, "*Museum Exhibition - Theory and Practice*", P (54).

2.6. Conclusion.

Museum buildings are built based on delivering a certain message to its visitors, through a different types of experience, which could be gained by the interactions between the visitor's and the museum spaces that could be described in three main contexts (personal – social - and physical). Each context has a deep relation with the museum envelope design and its internal spaces. The physical context is mainly about the museum architecture, interior design, exhibition hall, exhibits, and the way they are displayed in, which was highlighted through the explanation of the museum spaces, including location, zoning, entrances, circulation routes, in addition the design of the museum hall, the types of artifacts to be displayed, main strategies display. The personal and social contexts are mainly about the visitors themselves, their life experience, interests, motivations…etc., and the way their experience could be changed if the visitor is alone during the visit or in a group of people, which were explained through recognizing the visitor's characteristics, movement styles, behaviours, and traffic flow.

As a result of the new technologies took place at the end of 20^{th} century, new automated design concept and software have been utilized in the architectural design field, with new matured design solutions and methodologies, which made a great influence on the design of many buildings, especially museum design, which will be highlighted in the following chapters.

Chapter 3: Design by Algorithms

3.1. Introduction.

3.2. Brief history about Algorithms.

3.3. Algorithms Definitions & Characteristics.

3.4. Expressing Algorithms.

3.5. Types of Algorithms applied in the Architecture field.

- 3.5.1. The Commonly used Algorithms.
- 3.5.2. Analytical methods based on Algorithms (Space Syntax).
- 3.5.3. Algorithms written for certain purposes.

3.6. Architectural design by Algorithms.

- 3.6.1. Generation application.
- 3.6.2. Permutation application.
- 3.6.3. Optimization application.
- 3.6.4. Simulation application.
- 3.6.5. Transformation application.

3.7. Conclusion.

3.1. Introduction.

At the end of the 19th century, contemporary architecture has been influenced by the new achievements in the design technology and problem solving techniques. New developments have been introduced; because of the information and communication revolution in the field of computer design techniques, which presented a new clarification to the relationships between matter and data.In addition to that, integration between many disciplines of science has changed the world vision about the future in various fields. New forms characterized and rendered digitally including surfaces, complex curvilinear forms, shells and skins emphasized new concepts and trends in the contemporary architecture, generated by computer. It became the main generative design tool for most of architects nowadays. This tool helped the architects to change the traditional forms of architecture, and generate new ones' through new computational methods.

In search for new developed forms of buildings, computer presented new approaches for architects by Digital design. Digital design now is not limited to the use of software programs such as 3DS Max and Maya, but it became more developed as it could be applied using some codes and scripts, as in figure (3.1). Those codes are simplified form for implementing new ideas digitally, including Mel script, Max script and GOI script under Rhinoceros program, which has become more effective by using Grasshopper plug-in. These types of codes and scripts are not only used for general design application such as (graphic design, modeling, animation…etc.), but also has made a huge development in the architectural design. Accordingly, new computational architecture have been introduced, including isomorphic, animated, parametric , and metamorphic architecture(1).As using a computer always means to activate an algorithmic procedure (as mediator between input and output; architects start to study algorithms, in order to generate new complicated forms. Algorithms have become the easiest and the most powerful 3D modeler to create an architectural design based on a computational tool, unlike the traditional design methods. Due to the significant role algorithm carried out; new generation of forms appeared, such as the Guggenheim Museum in Bilbao, Experience Music in Seattle by Frank Gehry, and Blob architecture which is presented by Greg Lynn in 1998 (2).

Figure 3.1 Digital design.
Source: Done by the researcher.

(1) Kolarevic, B., "*Digital Morphogenesis and Computational Architectures*", University of Pennsylvania, 2000.
(2) Gross, Mark D, "*FormWriter - A little programing language for generating three dimensional form Algorithmically*", P (577-578).

The main concept of the digital design in architecture underwent several stages till it reached its current form. The first stage is based on trials of automated design, and the second stage is based on generating forms, which provides solutions for many design problems based on algorithms, scripts and consequently parametric design.

During the design process, scripts are run under computer based program with variable and parametric inputs, and the results are not always the same, due to the changes of inputs(1). A well designed script based on its type may end automatically after the solution is found. From the architectural perspective, those new design solutions are implemented to solve many of the design problems in terms of the main design aspects including form, function, economy and time. In addition, the main architectural design steps include generation, permutation, optimization, simulation and transformation .This new digital approach could be generally applied to many types of buildings.

3.2. Brief history about Algorithms.

The start of using the word Algorithm backs to the 9th century by Mohamed Al-Khwarizmi(2). He is one of the most known Muslim scientists in the field of mathematics.His books including“*Al-Kitab Al-Mukhtasar fi Hisab Al-Jabr w ’Al-Muqabala”*and “*On Calculation with Hindunumerals”*translated into many languages formed the base for the science of mathematics in the period Europe was living its darkest ages. These books emphasized new words in the field of mathematics like *Algebra*&*Algorithm*. Algorithm word is the English translation of the word Algoritmior Algorismus which is a Latin word means “the calculation method”. The first use of it was inthe Latin translation in the 12th century ofthe original book about the Hindu numerals which is lost and the only copy was found in Latin named with “Algoritmi de numeroIndorum”(3).

Algorithms are considered to be one of the preferred approaches to get information or generating a solution for any problem using some finite steps operated by a computer program. Consequently, using a computer program usually means to operate an algorithm and the outputs mainly depend on the inputted data; which is similar to the Turing machine(4).

(1)From:
- Sipser, M., “*Introduction to the theory of computation*”, p1-2.
- Ibid, Gross, D. and Mark, D., p 577-578.

(2)**Mohamed Al-Khwarizmi: -** Abu Ja’far Muhammad Ibn Musa Al-Khwarizmi “Father of Algebra” (790 - 850). He is a Persian pioneer mathematics and astronomy, and his writings influenced the math field from the medieval till now. He is also known as Al-Khwarizmi.

(3) From:-
- Al Daffa’, Ali Abdullah, “The Muslim contribution to Mathematics”, P (13-44).
- G. Donald Allen, “*Islamic Mathematics and Mathematicians*”.

(4)Ibid, Kotnik. T, P (17-21).

Turing machine[1], as shown in figure (3.2), was one of the earliest and most effective ways to simulate the idea of computability and logic which give the rise later to computer development. It is a tool for solving problems by following some instructions through symbolic means.
Algorithm process could be described as a Turing machine; starting with an input data or device and process to generate the output or store it for another operation, as shown in figure (3.3). Turing machine working as a convincing base for a theory of algorithms and are also used as a base for efficient analysis of algorithms.

Figure 3.2 Visualization of Turing machine.
Source: -Kotnik. T, "*Algorithmic Extension of Architecture*", P (19).

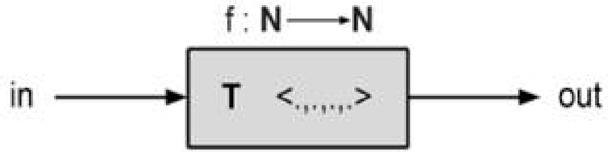


Figure 3.3Algorithm process description as the Turing machine.
Source: - Kotnik. T, "*Algorithmic Extension of Architecture*",P (21).

3.3. The Definitions & Characteristics of Algorithms[2].

Theoretically, the solution of any problem will be produced in case of the problem could be defined in a logical form.

Traditionally, Algorithm is the logical or the mathematical solutions for a specific problem. These solutions became more practical in case it could be implemented by computer.

Practically, the ordered set of instructions given to the computer in a specific form explaining the steps to solve any problemis called Algorithm. That makes algorithm the key of making the computer understand and operate these instructions.

[1]**Turing machine: -**It was first expressed in 1936 by Alan Turing, which published on paper for Hilbert's problem. A Turing machine consists of an infinite one-dimensional tape divided into cells, a movable read-write head with a specified starting position, and a table of transition rules. Each cell of the tape contains one symbol, either 0 or 1, and the head can move along the tape to scan one cell at a time and perform three different activities:

- READ: read the content of the cell,
- WRITE: change the content into the opposite, and
- MOVE: advance to the next cell to the right or left along the tape.

[2]Terzidis. K, "*Algorithmic Architecture*", P (38 - 60).

In the design process, Algorithms could be used for solving, organizing, or exploring problems with an organized complexity and in its simple form; the computational algorithm uses numerical methods to address problems.
Algorithm became a reflection to the human's mental processes in order to simulate and observe the human and machine behavior using some individual operations.

"An algorithm is a computational process defined by a Turing machine"(1).

"An algorithm is a well-ordered collection of unambiguous and effectively computable operations that when executed produces a result and halts in a finite amount of time"(2).
By this definition, we can identify the five important characteristics of algorithms as followed:

- **Algorithms are well-ordered.**
  The correct order to execute the instructions in order to obtain the required result is most important, especially in the operations performed by computer.
- **Algorithms have unambiguous operations.**
  Each operation in an algorithm must be sufficiently clear so that it does not need to be simplified.When an algorithm is written in computational primitives, then the algorithm is unambiguous and the computer can execute it.
- **Algorithms have effectively computable operations.**
  Each operation in an algorithm must be doable; the operation must be something that is possible to do.
- **Algorithms produce a result.**
  Inthe simplest definition of an algorithm, it was stated that an algorithm is a set of instructions for solving a problem. Unless an algorithm produces some result, the final result is likely to be correct.Only algorithms which produce results can be verified as either right or wrong.
- **Algorithms halt in a finite amount of time.**
  Algorithms should be composed of a finite number of operations and they should complete their execution in a finite amount of time.

3.4. Expressing Algorithm.

Algorithms could be expressedin many forms of codes, including natural language, pseudo code, flowchart, programing language. Those languages are the most commonlyused, and the ability to use which one of them depends on the purpose of utilizing such algorithm and its effectiveness and the required degree of accuracy, as shown in figure (3.4).

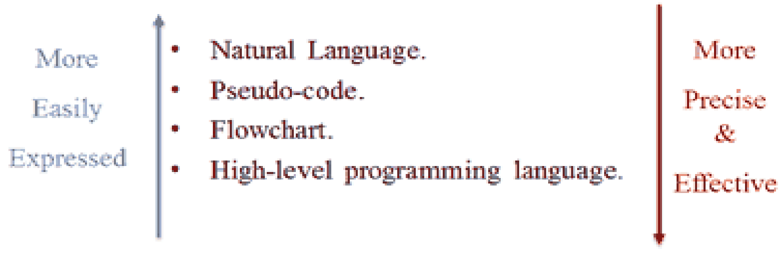


Figure 3.4 Algorithm languages between easily and effectively.
Source: - Done by the researcher

(1)Gurevich, Y, "*The Universal Turing machine – A half century survey*", P (377).
(2) Schneider, M. and J. Gersting, "*An Invitation to Computer Science"*, P (9).

A. Natural language.

Natural language is the commonly used language for general purposes. It uses the plain English in writing instructions, but it is usually verbose,ambiguous and wordy; so it is rarely used in technical algorithms.

B. Pseudo code.

Pseudo code is a combination of English and programming constructs; based on selection (if, switch) and iteration (while, repeat) constructs found in high-level programming languages; that make it a bite like programing language, as shown in figure (3.5). It is also avoids most issues of ambiguity, vaguely resembles common elements of programming languageswith no particular agreement on syntax.

```
procedure Search (List, TargetValue)
if (List empty)
   then
     (Declare search a failure)
   else
     (Select the first entry in List to be TestEntry;
      while (TargetValue [illegible] TestEntry and
                there remain entries to be considered)
          do (Select the next entry in List as TestEntry.);
      if (TargetValue = TestEntry)
          then (Declare search a success.)
          else (Declare search a failure.)
     ) end if
```

Figure 3.5 Pseudo code algorithm writing sample.
Source: - Computing Studies Syllabuses , “*Methods of Algorithm Description*”.

C. Flowchart.

Flowchart is a diagrammatic way for expressing algorithms and showing graphically the flow of controlled instruction in an algorithm, figure (3.6) shows the common shapes used in flowcharts. It avoid most (if not all) issues of ambiguity, difficult to modify w/o specialized tools, and largely standardized.

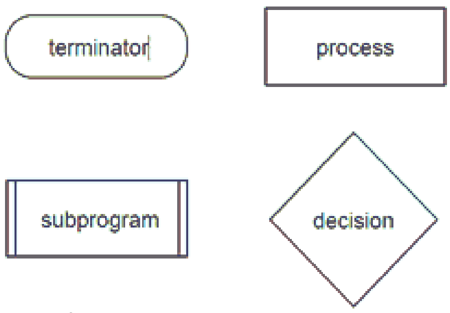


Figure 3.6 The common shapes used in flowcharts and its usage. **Source: -** Computing Studies Syllabuses , “*Methods of Algorithm Description*”.

D. Programing language.

It is the form of instruction which the machines could understand. It makes the communication between the human and the computer more easily by using a structured algorithm written in this language. Tend to require expressing low-level details that are not necessary for a high-level understanding.

3.5. Types of Algorithms applied in the Architecture field.

Duo to the wide application of algorithms in architectural design for a long time; algorithms havebecame more developed to fulfillthedesign requirements. Some of the used algorithms are commonly used than others, some of algorithms are written for solving a certain problem or for generating a special form used for a special project and analytical methods built by algorithms.

3.5.1. The Commonly appliedAlgorithms.

A. Voronoi Algorithm.

- **Definition.**

A Voronoi diagram[1] is *"The partitioning of a plane with*^{n}*points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other"*[2], as shown in figure (3.7). Voronoi diagram is also known as a *Dirichlet tessellation*;cells are called Dirichlet regions, and Thiessen polytopes, or Voronoi polygons[3].A Voronoi diagram is a geometric structure that represents proximity information about a set of points or objects.

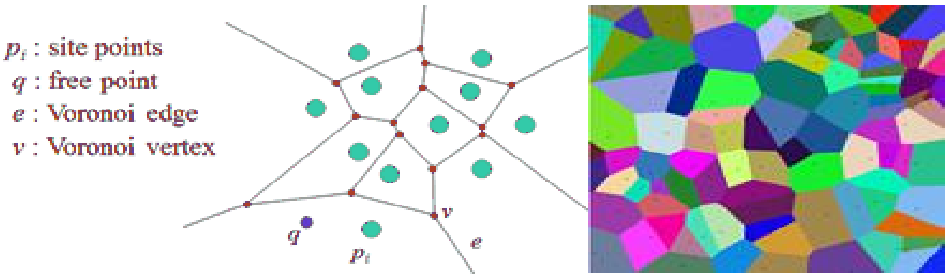


Figure 3.7A Voronoi diagram – the partitioning of plane
Source: - Sarvottamananda, S, "*Voronoi Diagrams*".

Voronoi diagram occurs in nature in many different biological 3d forms such as bone cells, soap bubbles, sponges, honey hexagonal, plants leaves, animal's skin and insect's wings, as shown in figures (3.8).

---

[1] **Voronoi diagram: -**Voronoi diagrams are named after Ukrainian mathematician GeorgyVoronoy|GeorgyFedosievychVoronyi (or *Voronoy*) who defined and studied the general *n*-dimensional case in 1908. Voronoi diagrams that are used in geophysics and meteorology to analyse spatially distributed data (such as rainfall measurements) are called Thiessen polygons after American meteorologist Alfred H. Thiessen. In condensed matter physics, such tessellations are also known as Wigner–Seitz unit cells. Voronoi tessellations of the reciprocal lattice of momentaare calledBrillouin zones. For general lattices in Lie groups, the cells are simply calledfundamental domains. In the case of general metric spaces, the cells are often called metric fundamental polygons. Other equivalent names for it are: Voronoi polyhedra, Voronoi polygons, , Voronoi decomposition, Voronoi tessellations, Dirichlet tessellations. Voronoi diagrams can be found in a large number of fields in science and technology, even in art, and they have found numerous practical and theoretical applications. It was used by Dirichlet (1850) in the investigation of positive quadratic forms.

[2] Aurenhammer, F. and Klein, R, "Ch. 5-Voronoi Diagrams."Of "*Handbook of Computational Geometry*", P (201-290).

[3] Atsuyuki, O, Boots, B, Sugihara, K, Nok Chiu, S, "*Spatial Tessellations – Concepts and Applications of Voronoi Diagrams*", P (6 – 70).

Figure 3.8 Voronoi biological forms (sponges, honey hexagonal, bone cells, insect's wings, plants leaves, & animal's skin). **Source: -** neoarchbeta.wordpress.com/2011/05/07/voronoi-diagramsnature-and-architecture/

- **Formation& Characteristics.**

Given some number of points *S*in the plane, their Voronoi diagram divides the plane according to the nearest neighbor and each point is associated with the region on the plane closest to it.The final product of connecting each point with the others in the 2d or in the 3d will be the Voronoi diagram. The Voronoi nodes or these connected points are forming what is called Delaunay Triangulation(1), as shown in figure (3.9).

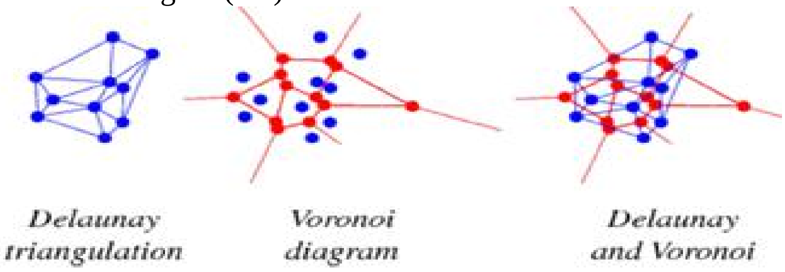


Figure 3.9 Voronoi diagram and Delaunay Triangulation
Source: - mathworld.wolfram.com/VoronoiDiagram.html

In the 2dplan lattice are giving different tessellations according to the point's distribution; consequently the Voronoi diagram modified according to the modification in the points set as shown in figure (3.10). In Voronoi cells the common segmentbetween any two cells is usually evenly divides the segment connecting the two cell's centers.

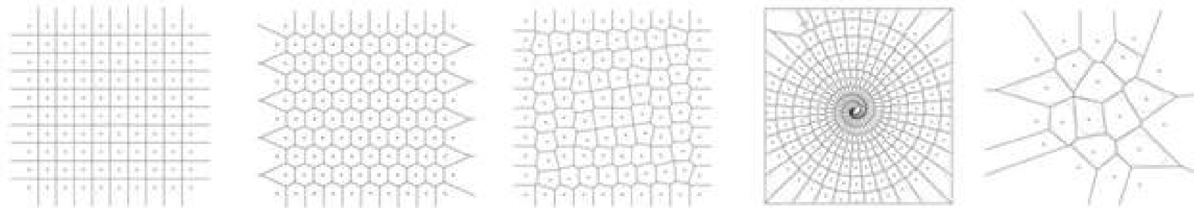


Figure 3.10 Voronoi cells in 2d plan
Source: object-e.net/uncategorized/algorithmicbody

(1)Ibid, Aurenhammer, F. and Klein, R.

- **General application[1].**

- A particularly notable use of a Voronoi diagram was the analysis of the 1854 cholera epidemic in London, in which physician John Snow determined a strong correlation of deaths with proximity to a particular (and infected) water pump on Broad Street.
- In materials science, polycrystalline microstructures in metallic alloys are commonly represented using Voronoi tessellations.
- In ecology, Voronoi diagrams are used to study the growth patterns of forests and forest canopies, and may also be helpful in developing predictive models for forest fires.
- In computer graphics, Voronoi diagrams are used to procedurally generate of organic-looking textures. In networking, Voronoi diagrams can be used in derivations of the capacity of a wireless network.Voronoi diagrams together with farthest-point Voronoi diagrams are used for efficient algorithms to compute the roundness of a set of points.

- **Architectural application.**

The concept of using Voronoi diagram could be implemented in generative forms and it produces very organic looking patternsto save time for Architects and Designers. Other applications in the field of architecture:

- **Space planning.**

It is also useful for space planning, (ex. For comparing areas covered by different hospitals, shops…etc.). With Voronoi diagram one can easily determine where is the nearest shop or hospital. Urban planners can study if certain area needs a new hospital.Voronoidiagram structural properties in 2d and 3d give it the priority to be used in such field. It could be used as a way to organize spaces or to subdivide it according to its closest neighbors. Duo tothe Voronoi ability to describe natural formations; it couldprovide architecture with new ways to organize and structure the space[2].

- **City Planning.**

Like Town planning in Architecture may be simplified by assigning the site as a nodal point and generating the Voronoi diagram as explained above.

[1]Mark de Berg, Marc van Kreveld, Overmars, M,Schwarzkopf, O , "*Computational Geometry*", P (148 – 167).
[2]Ibid, Atsuyuki, O and others, P (57 – 70).

B. Cellular Automata.

- **Definition.**

Cellular Automata is the plural of cellular automaton, abbreviated to CA.Cellular automata[1] "*is the computational method which can simulate the process of growth by describing a complex system by simple individuals following simple rules*"[2].The universe for cellular automata has evolved over a number of dimensions, Wolfram, one dimensional, Conway, two-dimensional, and Ulam, three-dimensional. The three-dimensional universe is the one that architects are most interested in.

CA mainly consists of a regular grid with any finite number of dimensions; each grid contains a cell having a finite number of states (*on&off*). Around each specified cell a set of cells called cell's neighborhoods, as shown in figure (3.11). Time is involved in the formula[3]with an initial state (*t*=0, 1…etc.), and it is selected by assigning a state for each cell. A new generation is created (*t* = 1), according to the formula, as shown in figure (3.12). Typically, the rule for updating the state of cells is the same for each cell and does not change over time, and applied to the whole grid simultaneously, though exceptions are known, such as the probabilistic cellular automata and asynchronous cellular automaton.

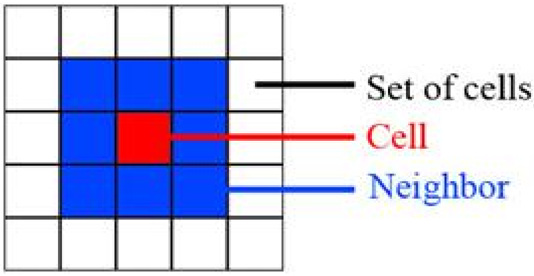


Figure 3.11A cell and its neighborhood. **Source: -** Done by the researcher.

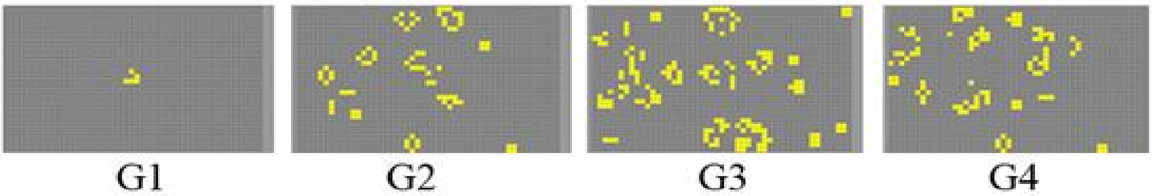


Figure 3.12 New generations formed during a set of time "Game of life". **Source: www.bitstorm.org/gameoflife/**

[1]**Cellular automata: -** The concept of simulating growth was introduced by Stanislaw Ulam and John von Conway in 1940s as an area for simulating multi-state machines. The concept gained greater after John Conway's "*Life*" game, which game is generating two-dimensional patterns and working according some rules: -
Game of life rules are: -

- A dead cell with exactly three live neighbors becomes a live cell (birth).
- A live cell with two or three live neighbors stays a live (survival).
- In all other cases, a cell dies or remains dead (overcrowding or loneliness).

In the 1980s, Stephen Wolfram engaged in a systematic study of one-dimensional cellular automata, or what he calls *Elementary cellular automata*; his research assistant Matthew Cook showed that one of these rules is Turing-complete.

[2]Krawczyk, R. J, "*Architectural Interpretation of Cellular Automata*".

[3]**CA formula: -**states that "*The state of a cell at time t is a function of the states of a finite number of cells or neighbors*".

CA could be found in the nature in the patterns of some seashells (like the ones in *Conus* and *Cymbiola* genus), are generated by natural cellular automata and in the Plants regulated intake and losing gases via a cellular automaton mechanism. Each stoma on the leaf acts as a cell[1].

- **Formation**

The concept of using CA in 2D& 3D formation is the same,as shown in figure (3.13) & (3.14). In the layout or in the universe an unlimited set of cells, those cells might be empty or occupied; each occupied cell is marked in the space of work defining its location. The transitional start by an occupied cell and then it process to reach a successful generation. CA is applying the same rules stated by Conway's in the game of life, andthe future of each cell depends on its neighborhood[2].

The behavior of a CAis prescribed by sets of rules and algorithms that dictate the relationships between elements within the system. The relationships between elements in the CA are iteratively re-evaluated based on these rules, providing the means for the system to adapt to internal and external changes.

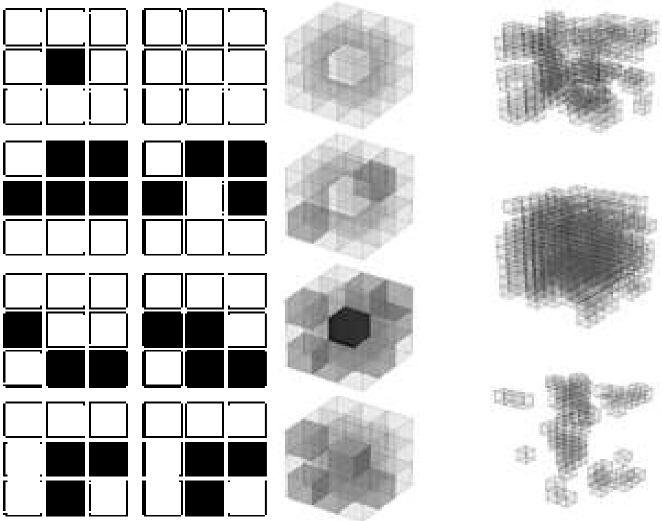


Figure 3.132D & 3D formation
Source:- Clarke, C and Anzalone, P, "*Architectural Applications of Complex Adaptive Systems*"

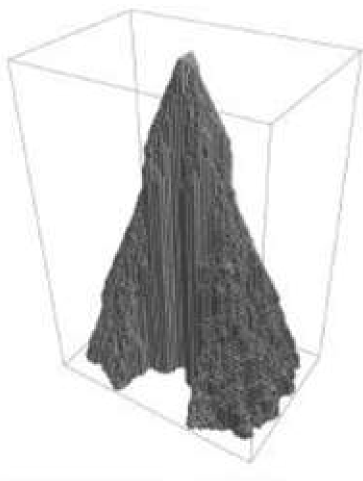


Figure 3.143D formation
Source: -Wolfram, S, "A new kind of science", P (180).

- **General application.**

- In computer processors for processing elements arranged in a regular grid of identical cells. The grid is usually a square tiling, or tessellation, of two or three dimensions; other tilings are possible, but not yet used. Cell states are determined only by interactions with adjacent neighbor cells.
- In Error correction coding; CA have been applied to design error correction codes.

[1]Peak, W, Messinger, Mott, "*Evidence for complex, collective dynamics and emergent, distributed computation in plants*".
[2]Ibid, Krawczyk, R. J.

- **Architectural application.**

- CA is becoming useful to architecture duo to its ability to generate patterns; from organized patterns it might be able to generate new architectural forms. CA viewed from a mathematical approach, and differs from traditional deterministic methods which make the current results (or generations) are the basis for the next results (or generations). This frequent substitution method continues until a certain state is achieved. Fractals and strange attractors are also created in a similar manner. Many digital methods in architecture are parametrically driven; an initial set of parameters is used to generate one result. If an alternative is chosen, the parameters need to be modified and the generation is repeated more. The difference between these two methods is that in parametric methods the results can be easily anticipated, while in recursive methods the outcome usually cannot. This offers an interesting and rich platform from which to develop possible architectural patterns.
- In the field of architecture, CA could be used for generating an architectural series of forms with a huge variations of unite shapes depends on the retained growth of vertical and horizontal volumes, using random sizes, offset, and vertices, as shown in figures (3.15).
- CA is also useful for solving urban and landscaping problems.

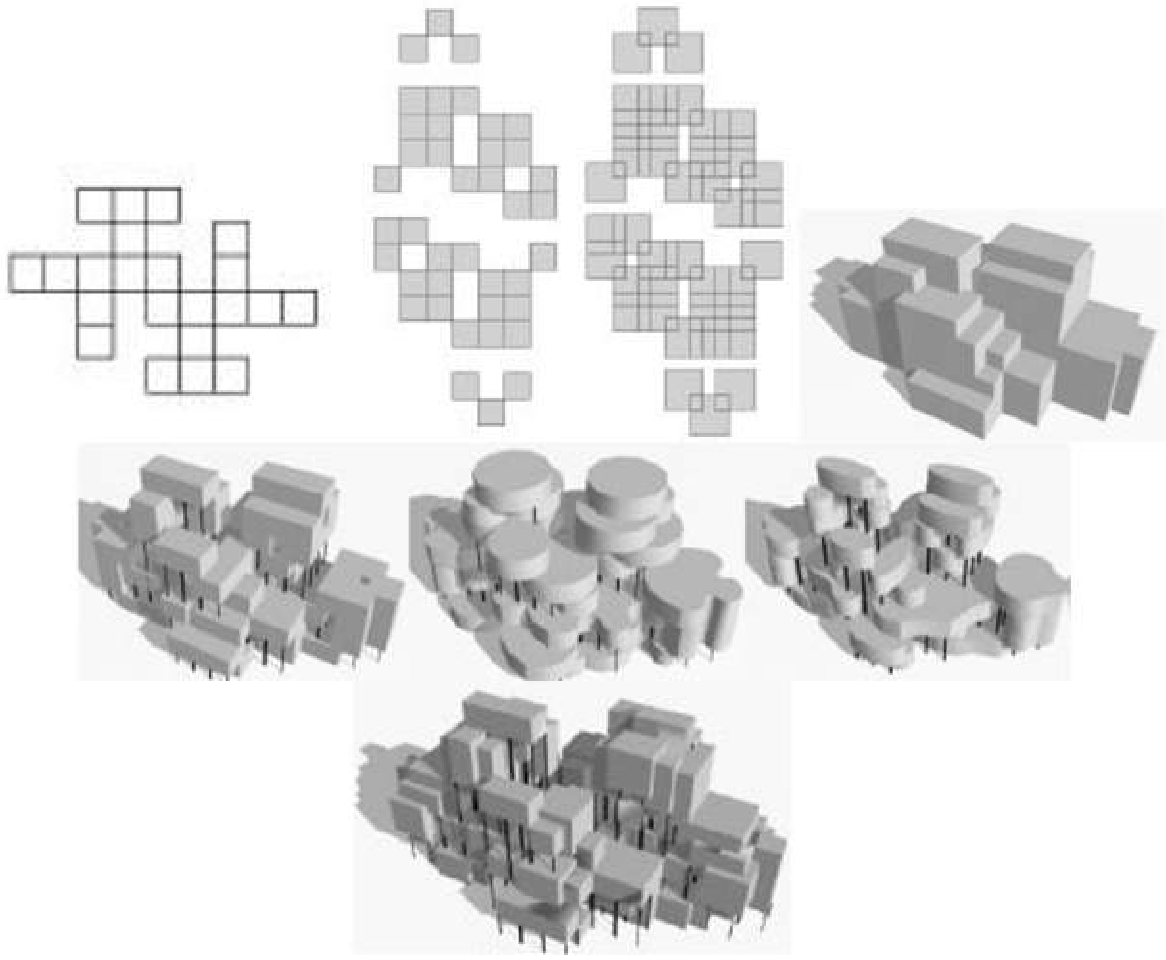


Figure 3.15 New architectural form generation.
Source: - Krawczyk, R. J, "*Architectural Interpretation of Cellular Automata*", P (3 -7).

C. Swarm Intelligence.

- **Definition.**

Swarm intelligenceor SI, isa scientific theory about how Complex and sophisticate behaviors can emerge from social creature group, or it is relatively the new branch of Artificial Intelligence;which has an inspired numerous algorithms used to model and control the collective behavior of decentralized social swarms in nature or self-organized systems, such as ant colonies, fish schooling, honey bees, and bird flocks[1], as shown in figures (3.16).The biological view of SI was a result to the insights about the incredible abilities of social insects to solve their everyday-life problems, which make many scientists in many fields to search for how they could use this swarm[2]. Since the computational modeling of swarms was proposed, a new successful application of Swarm Intelligence algorithms in several optimization tasks and research problems appeared.

Figure 3.16 Swarming in nature (fish schooling, honey bees, and bird flocking).
Source: - Cui. X, "*Swarm Intelligence, Bio-inspired Emergent Intelligence*".

SI means more set of algorithms; which is presented by Craig Renolds in 1986 simulating the birds flocking and animals schooling behaviour. The basic flocking model consists of three simple steering behaviors which describe how individual bodies maneuvers based on the positions and velocities of its nearby flock mates using four algorithms in pseud code form starting with bodies algorithm, as shown in figures (3.17), (3.18), & (3.19):

- Separation algorithm– separation: steer to avoid crowding local flock mates
- Alignment algorithm– alignment: steer towards the average heading of local flock mates
- Cohesion algorithm–cohesion: steer to move toward the average position of local flock mates.

---

[1]From: -

- Garnier.S, Gautrais.J and Theraulaz. G, "*The biological principles of swarm intelligence*".
- Glasgow. A.H. J, "*Swarm Intelligence: Concepts, Models and application – Technical report*".

[2]**Swarm Intelligence: -**In the past decades, biologists and natural scientists have been studying the behaviors of social insects because of the amazing efficiency of these natural swarm systems. In the late-80s, computer scientists proposed the scientific insights of these natural swarm systems to the field of Artificial Intelligence. In 1989, the expression "Swarm Intelligence" was first introduced by G. Beni and J. Wang in the global optimization framework as a set of algorithms for controlling robotic swarm. In 1991, Ant Colony Optimization (ACO) was introduced by M. Dorigo and colleagues as a novel nature-inspired Metaheuristic for the solution of hard combinatorial optimization (CO) problems. In 1995, particle swarm optimization was introduced by J. Kennedy et al, and was first intended for simulating the bird flocking social behavior. By the late-90s, these two most popular swarm intelligence algorithms started to go beyond a pure scientific interest and to enter the realm of real-world applications. It is perhaps worth mentioning here that a number of years later, exactly in 2005, Artificial Bee Colony Algorithm were proposed by D. Karabago as a new member of the family of swarm intelligence algorithms.

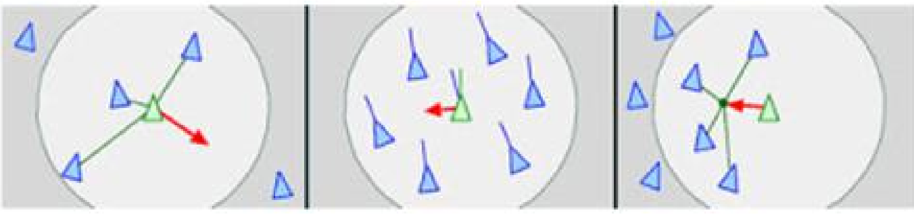


Figure 3.17 Craig Renolds simulation about bodies flocking.
Source: - IAAC / Digital Technologies in Architecture / 2007: swarm intelligence/architecture

```
Data: A group of boids.
Result: Simulates flocking behaviour with an animation.
foreach Frame do
  foreach boid do
    separation(boid);
    cohesion(boid);
    alignment(boid);
  end
  foreach boid do
    boid.x ← cos(boid.course) * b.velocity * dTime;
    boid.y ← sin(boid.course) * b.velocity * dTime;
    draw(boid);
  end
end
```

```
Data: A boid.
Result: The course of the boid is updated.
goal ← (0,0);
neighbours ← getNeighbours(boid);
foreach nBoid in neighbours do
  goal ← goal + positionOf(nBoid);
end
goal ← goal / neighbours.size();
steerThoward(goal, boid);
```

Boids algorithm   Cohesion

```
Data: A boid.
Result: The course of the boid is updated.
goal ← (0,0);
neighbours ← getNeighbours(boid);
foreach nBoid in neighbours do
  goal ← goal + positionOf(boid) - positionOf(nBoid);
end
goal ← goal / neighbours.size();
steerThoward(goal, boid);
```

```
Data: A boid.
Result: The course and velocity of the boid is updated.
dCourse ← 0;
dVelocity ← 0;
neighbours ← getNeighbours(boid);
foreach nBoid in neighbours do
  dCourse ← dCourse + getCourse(nBoid) - getCourse(boid);
  dVelocity ← dVelocity + getVelocity(nBoid) - getVelocity(boid);
end
dCourse ← dCourse / neighbours.size();
dVelocity ← dVelocity / neighbours.size();
boid.addCourse(dCourse);
boid.addVelocity(dVelocity);
```

Separation   Alignment(1)

Figure 3.18 Craig Renoldsbodies flocking algorithm.
Source: - Erneholm. C. O, "*Simulation of the Flocking Behavior of Birds with the Bodies Algorithm*"

(1)**Separation: -**
Gives an agent the ability to maintain a certain separation distance from others nearby. This prevents agents from crowding to closely together, allowing them to scan a wider area. To compute steering for separation, first a search is made to find other individuals within the specified neighborhood. For each nearby agent, a repulsive force is
Cohesion: -
Gives an agent the ability to cohere (approach and form a group) with other nearby agents. Steering for cohesion can be computed by finding all agents in the local neighborhood and computing the "average position" of the nearby agents. The steering force is then applied in the direction of that "average position".
Alignment: -
Gives an agent the ability to align itself with other nearby characters. Steering for alignment can be computed by finding all agents in the local neighborhood and averaging together the 'heading' vectors of the nearby agents. This steering will tend to turn our agent so it is aligned with its neighbors.
Computed by subtracting the positions of our agent and the nearby ones and normalizing the resultant vector. These repulsive forces for each nearby character are summed together to produce the overall steering force.

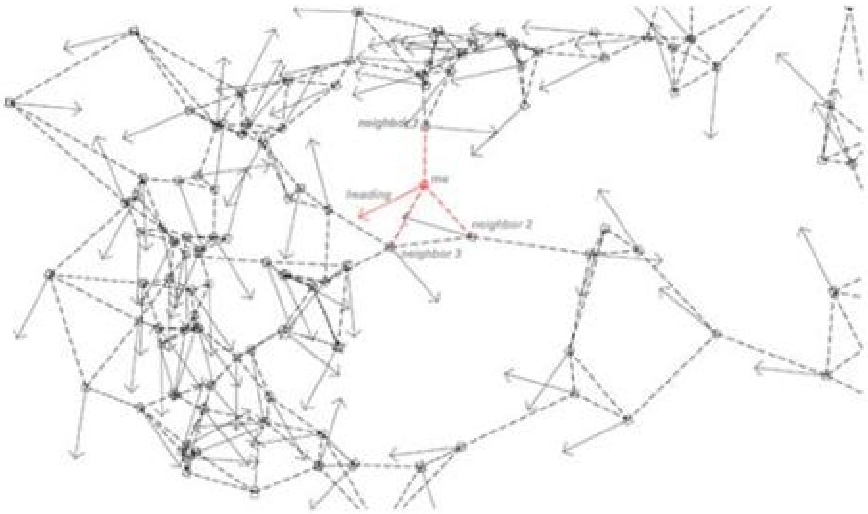


Figure 3.19 Diagram of Swarm Arrows represent each agent's heading, dotted lines their closest neighbors.
Source: - Carranza. P. M, Coates. P, "*The use of Swarm Intelligence to generate architectural form*".

- **General application.**

As the single ant or bee aren't smart but their colonies are.The study of swarm intelligence is providing insights that can help humans manage complex systems, from truck routing to military robots(1).

Computational modeling of swarms has been further applied to a wide-range of diverse fields, including robotics swarm and Nano robotics, machine learning, nanotechnology, molecular biology and medicine informatics, dynamical systems and operations research in the field of finance and business, traffic and crowd control, military tactics, and even interactive art(2).

- **Architectural application.**

The complexity in our cities is the human interaction; this can be related with the interaction of thousands of different species in thenature. Swarm architecture feeds on data derived from socialtransactions. Swarm architecture is aTrans –architecture; this is due to it builds new transaction spaces, transactive,emotive,interactive and collaborative at the same time. When the architects look from the point of view of Swarm Architectureto an urban environment; they couldn't see it as an isolated objects, but it became having a relation with each other's. Swarm Architecture is more challenging for the urban planner to find new rules for generating cities' planes, and also helping the architects to simulate how the human movement will be inside each space they design. Swarm architecture has some difficulties when applied on the human movement; as the human movement couldn't be predictable or controlled.

(1)Miller. P, "*Swarm Theory*".

(2) Artists are keen on using swarm intelligence algorithm technology to simulate the moving of crowds. The first use of swarm technology in movies was in "*Batman Returns*" to simulate and render the movement of a group of penguins. The same concept became common in the world of movies depending on groups of animals or creatures in carton movies like "*Lion King*", or for crowds of people like in "*The Mummy Return*", "*The lord of the Rings - the two towers & the return of the king*".

D. Stochastic Search (Optimization).

- **Definition.**

Global optimization algorithms are often classified into Deterministic and Stochastic. Stochastic optimization or SO or Monte Carlo method is an optimization method; whichis referring to an algorithm that generatesand uses random variables (such as pseudo-random number generator). Stochastic optimization methods also include methods with random iterates to solve stochastic large problemsefficiently; which can't be solved using deterministic algorithm used for deterministic problems(1).

Stochastic Search is known as "*The random search in space until a given condition is met*"(2).

Stochastic search algorithm is commonly used to place objects in a random way within a set depending on a previously defined condition. This computer aid is helping designers to generated solutions and evaluates it at the same time. Despite it requires a huge number of calculations to find a solution; the probability to find a suitable one is decreased more as the search space is reduced.

- **General application.**

Stochastic search and optimization techniques are used in many fields including:

- Aerospace in the design of a missile or aircraft.
- Medicine in determining the effectiveness of a new drug.
- Transportation in developing the most efficient timing strategies for traffic signals.
- Finance for making investment decisions in order to increase profits.
- Stochastic algorithms can help researchers and practitioners devise to find optimal solutions to countless real-world problems(3).

- **Architectural application.**

The architectural form generation processis also affected by this new technology. The use of such technology allowed designers to take advantage of the potential of the computer processor to perform a very large number of calculations manipulating many entities; to get an unlimited number of variations in architectural form. The process of generating architectural form through code made some changes in the role of the designer from being a form-maker to be a rule-builder or a breeder of architectural forms(4).

(1) From:
- Spall, J. C, "*Introduction to Stochastic Search and Optimization – Estimation, Simulation, and Control*",P (1 - 30).
- Zabinsky. Z. B, "*Stochastic adaptive search for global optimization*", P (20).

(2)Ibid, Terzidis. K, P (84).

(3) Ibid, Spall. J. C, back cover.

(4)Cardoso. D, "*Controlled unpredictability: Constraining Stochastic Search as a Form-Finding Method for Architectural Design*".

E. Genetic Algorithm.

- **Definition.**

Genetic Algorithm[(1)] or GA is the heuristic artificial intelligence; which simulates the process of natural evolution in generating useful solutions for search problems. GA belongs to the class of stochastic search methods a larger class of Evolutionary Algorithms EA, as shown in figure (3.20); which generate solutions to optimization problems using some techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover[(2)(3)].

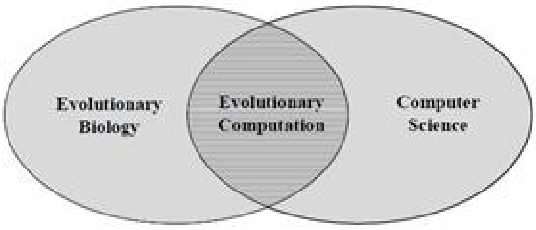


Figure 3.20 Evolutionary Computation and Evolutionary Design a result of combining Computer Science and Evolutionary Biology.

Source: - Bentley. P, "*Aspects of Evolutionary Design by Computers*".

GA helps the designer to take decisions in the shortest time by performing the same operation done in population to select the best solution appears through generation. To start the algorithm, a solution to the problem should be presented at first. The algorithm then will create a population of solutions and applies genetic operators; such as mutation and crossoverto evolve the solutionsbased on a fitness function in order to find the best solution.Atfirst identify the population of chromosomes which represent the possible solutions of the problem. Then the second step will be the selection which refers to a part of the population that will evolve to the next generation. After that another selection will be performed to determine howgood the solution is[(4)]. GA is using two separate spaces in this process to generate the best solution[(5)], as shown in figure (3.21):

- The search space or the space for the coded solution to the problem (the genotype).Each genotype has some coded parameters or genes with a value known as alleles. Genotypes are working as parents.
- The actual solutions space (the phenotype). Each phenotype contains a collection of coded parameters based to it from the genotype genes, as shown in figure (3.22). Phenotypes are known as children to the genotype parents.

[(1)]**Genetic Algorithms: -** were invented by John Holland in the 1960s and since then they havebeen used as stochastic methods for solving optimization and search problems, operating on a population of possible solutions. According to Darwin's Theory of Evolution, the repetitive application of the aforementioned procedures alters an initial species into various other species; however, only the stronger prevail.

[(2)] Michal. G. K, Houck. C. R, Joins. J. A, "*A Genetic Algorithm for Function Optimization: A Matlab Implementation*", P (2).

[(3)]**Crossover**: - refers to the combination or exchange of characteristics between two members of the elite group defined by selection, by which offspring is produced. There are various types of crossover but the most frequently used are: the one-point crossover, in which the parents are cut at a specific point and the head of the first is pasted to the tail of the second or vice versa; and the two-point crossover, in which a part from one of the parents is obtained and exchanged with the part that lies in the same location of the other parent.

[(4)]Eleftheria. F, "*Genetic Algorithms in Architecture: A Necessity or a Trend?*".

[(5)]Ibid, Bentley. P, P (8 - 9).

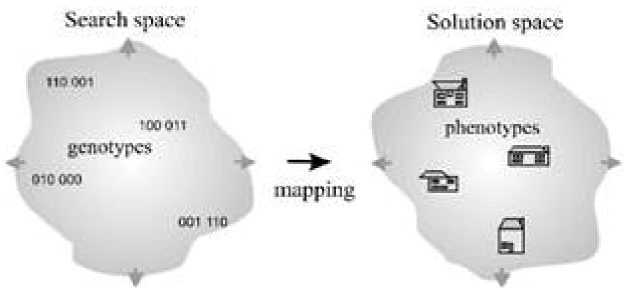


Figure 3.21 The GA spaces, genotype and phenotype.
Source: - Bentley. P, "*Aspects of Evolutionary Design by Computers*",P (9).

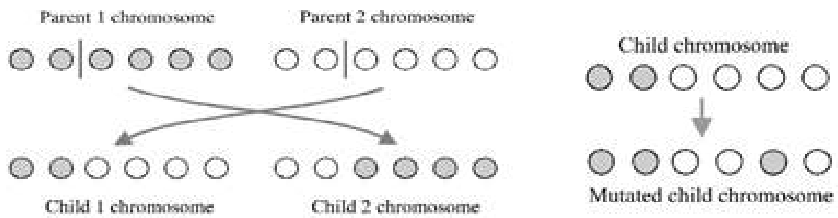


Figure 3.22 Parents and child chromosome.
Source: - Bentley. P, "*Aspects of Evolutionary Design by Computers*", P (10).

- **General application.**

Genetic algorithms application could be found in bioinformatics, phylogenetic, computational science, engineering, economics, chemistry, manufacturing, mathematics, and physics. GA is involved also in the industrial design especially in furniture design; it helps in choosing the sufficient design, materials, structural and functional details.

- **Architectural application.**

Using evolutionary computation in architecture considered as an important move in the field of art.The use of evolutionary design has classified into four main categories, as shown in figure (3.23) based on evolving morphologies and control systems of artificial life(1).

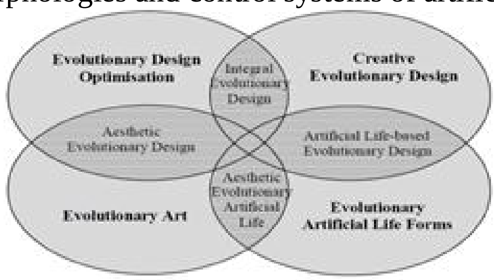


Figure 3.23 Evolutionary design categories by GA.
Source: - Bentley. P, "*Aspects of Evolutionary Design by Computers*", P (11).

GA was introduced in field of architecture design to address problems of complexity in function and form of architectural projects from scratch, among many other evolutionary techniques, has been used in architecture as optimization tools or as form-generation tools. The plans and forms generated by GA are considered to be artificial solutions.

(1)Ibid, Bentley. P, P (36).

F. A* algorithm.

- **Definition.**

Or A star[1]; is referring to the least cost path between two given nodes in the space, one of them is the start and the other is the target. As A* traverses the graph, it follows a path of the lowest knownheuristic[2]cost, keeping a sorted priority queue of alternate path segments along the way.It is a Pathfinder tool to discover plan's design problems[3]. The planning with pathfinders is different than acting with movement algorithms, as shown in figure (3.24).

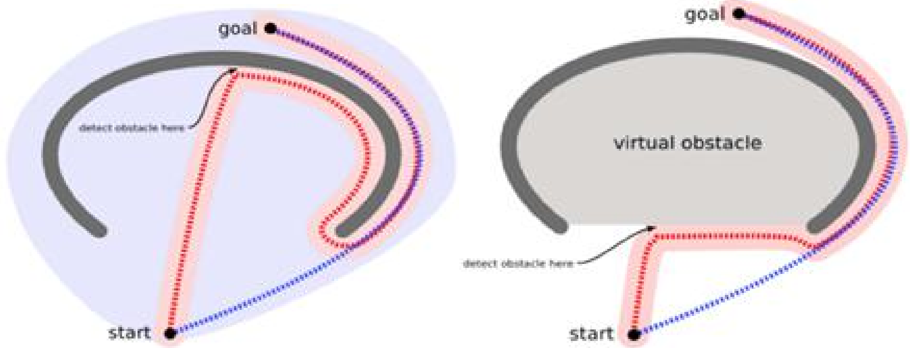
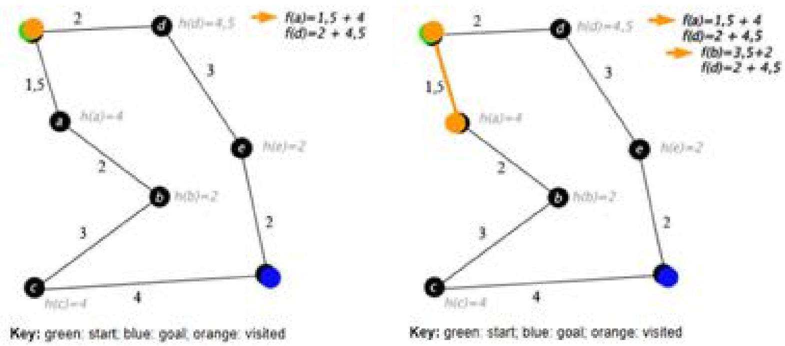


Figure 3.24 Path finding from start point to the goal. **Source:** theory.stanford.edu/~amitp/GameProgramming/AStarComparison.html

A* path calculation method is presented by an equation f (n) = g (n) + h (n). When g(n) represents the cost of the path from the starting point to any vertex n and h(n) represents the heuristic estimated cost from vertex n to the goal. Each time through the main loop for every step, it examines the vertex n that has the lowest f (n), as shown in figure (3.25).



[1]**A* algorithm: -** was first described by Peter Hart, Nils Nilsson and Bertram Raphael of Stanford Research Institute (now SRI International) in 1968. It is an extension of EdsgerDijkstra's 1959 algorithm. A* achieves better performance (with respect to time) by using heuristics.

[2]**Heuristic: -**refers to experience-based techniques for problem solving, learning, and discovery. Where the exhaustive search is impractical, heuristic methods are used to speed up the process of finding a satisfactory solution; mental short cuts to ease the cognitive load of making a decision. Examples of this method include using a rule of thumb, an educated guess, an intuitive judgment, or common sense. In more precise terms, heuristics are strategies using readily accessible, though loosely applicable, information to control problem solving in human beings and machines.

[3]Judea, Pearl, "*Heuristics: intelligent search strategies for computer problem solving*".

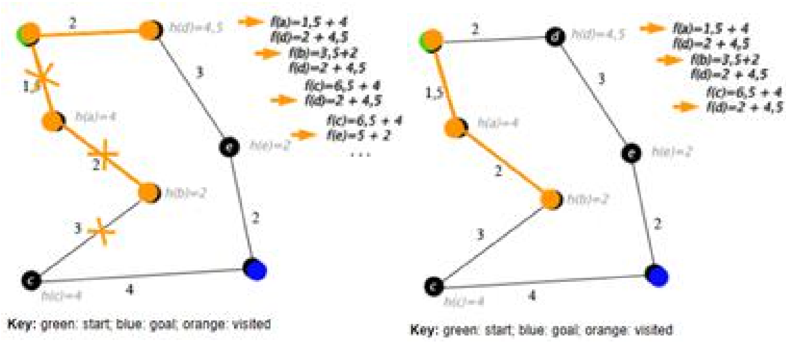


Figure 3.25A* algorithm example.

Source: - Delling. D, Sanders. P, Schultes. D, Wagner. D, "*Engineering Route Planning Algorithms*".

The algorithm is working on every node along the path by getting f (x) for the first point, then the next point. If found a lower f (x) value it will be removed from the queue and get another with higher priority until the main path is presented, as shown in figures (3.26) & (3.27).

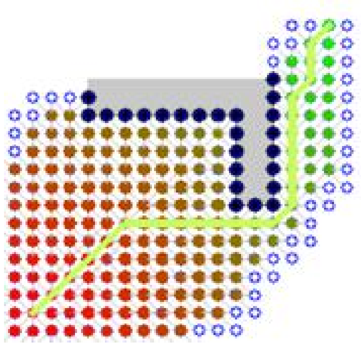


Figure 3.26 A* Algorithm example.
Source: - Delling. D, Sanders. P, Schultes. D, Wagner. D, "*Engineering Route Planning Algorithms*".

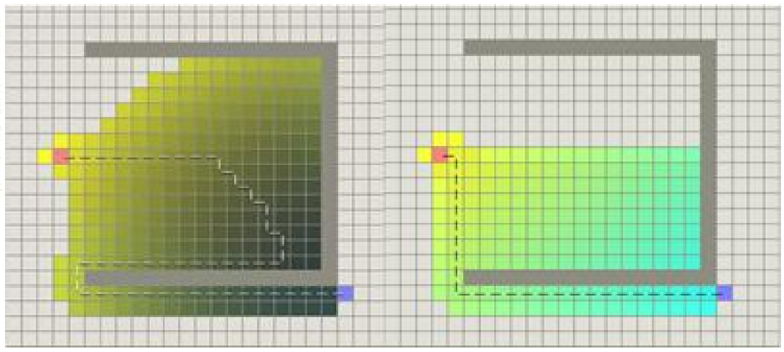


Figure 3.27A* algorithm example.
Source:-
theory.stanford.edu/~amitp/GameProgramming/AStarComparison.html

- **General application.**

It could be used in the way finding in most of computer games, and to value the games squares if it is difficult or easy to be found.

- **Architectural application.**

A* algorithm could be used for simulating people movement in the architectural spaces of a specific building and solving many of the design problems, or it could be used in urban design for studying the pedestrians and vehicles movement pattern. It helps the designer to study the building users movement patterns, in addition to their movement in case of fire, and other special cases before finishing the design[1].

[1]Judea, & Pearl, "*Generalized best-first search strategies and the optimality of A**".

3.5.2. Analytical methods based on Algorithms (Space syntax).

- **Definition.**

Space syntax[1] is a theory about space and human behavior; analyzing human interaction in the built environment and examining the impact of accessibility in spatial layouts, build spaces, and urban places on human behavior, communication and interaction[2]. Space syntax and related methods of analysis are important to universal design; as it provides a theoretical perspective for understanding accessibility and spatial layout, and provides methods for analyzing the relative accessibility of alternative design choices.Researches using space syntax approach shows how[3]:

- Movement patterns are powerfully shaped by spatial layout.
- Patterns of security and insecurity are affected by spatial design.
- Spatial segregation and social disadvantage are related in cities.
- Buildings can create more interactive organizational cultures.
- Museum layout on use and satisfaction.
- This relation shapes the evolution of the centers and sub-centers that makes cities livable.

The relation between spaces inside any building or in an urban space depends on the relation between the human configuration and spatial configuration[4]. The arrangement of spaces according to their use will affect the movement pattern; which might vary from design to another, as shown in figure (3.28). There are two approaches to the analysis of space syntax, the first is by examining patterns ofconnections (graph-based), and the second is by analyzing perceived spatial relations (geometry-based). Graphs consist of nodes (vertices) and edges (lines). In the graph-based system, the integration of a space, a measure of its accessibility or centrality, is expressed as distance, so that a more integrated space is less distant from other spaces. Since the system standardizes these measures, spaces can be compared to one another or to ideal regular patterns known as benchmarks. However, analysis of open spatial plans with ambiguous boundaries is more difficult than cellular plans. Spaces are classified as one-dimensional paths of movement or as places inviting prolonged occupation.

(1)**Space syntax: -**originated as a research method in the 1970s at the University of London as a way to record movement and interaction within cities and buildings. The set of analytical techniques called "syntactic" were used by Hillier and Hanson in The Social Logic of Space (1984) to explore the impact of space on social behavior and relationships. Since that time, it has developed into a coherent body of literature about human social interaction in the built environment.

(2)Hillier. B, "*Space is the Machine: a configurational theory of architecture*".

(3)From:

- Hillier. B& Iida. S, "*Network and psychological effects in urban movement, Proceedings of Spatial Information Theory: International*".
- Tzortzi. K, "*Museum Building Design And Exhibition Layout: Patterns of Interaction*".

(4)**Spatial configuration: -** is set of interdependent relations in which each is determined by its relation to all the others; which we live and move, and represent social organization as physical configurations of forms and elements that we see. Both social dimensions of building are therefore configurational in nature, and it is the habit of the human mind to handle configuration unconsciously and intuitively, in much the same way as we handle the grammatical and semantic structures of a language intuitively.

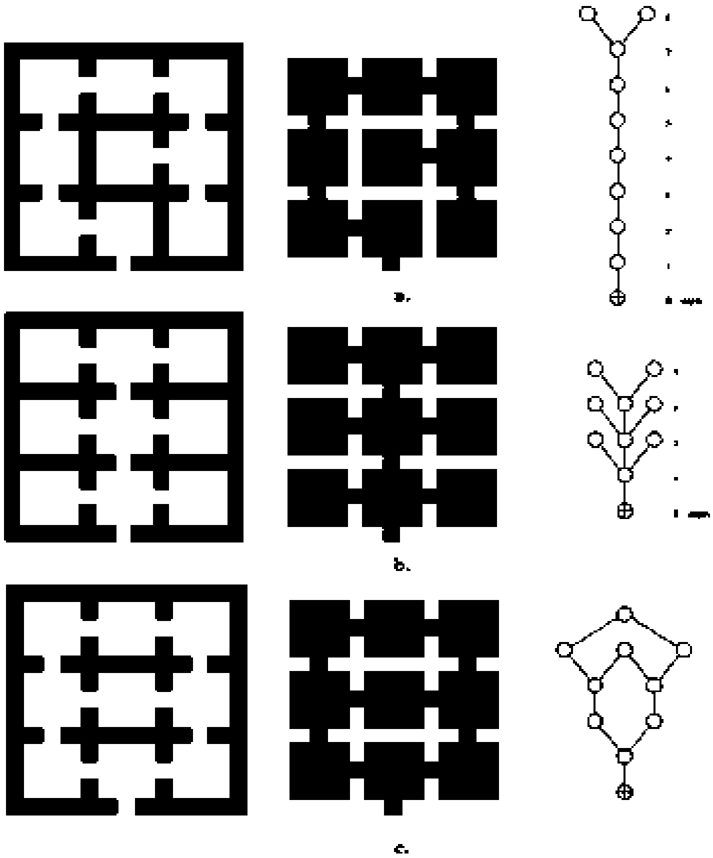


Figure 3.28 Spatial configurations and the change of movement pattern.
Source: - Hillier. B, "*Space is the Machine: a configurational theory of architecture*", P (21).

Spatial geometry is not just as the background for the human activity or for objects; it is the effective aspect of everything human beings do[1], as shown in figure (3.29).

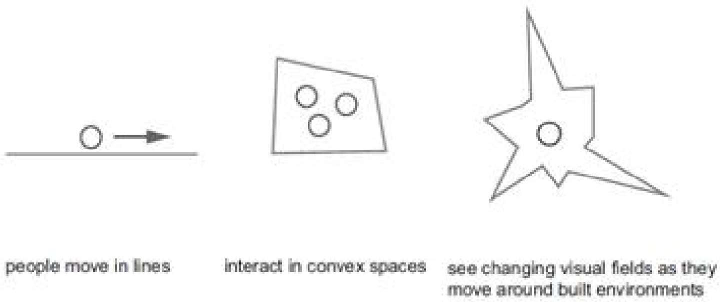


Figure 3.29 Human activity and spatial space.
Source: - Vaughan. L, "*The spatial syntax of urban segregation*".

There are three main conceptual approaches for describing space syntaxtechnically; depending on one and two dimensional aspects:

[1]Vaughan. L, "*The spatial syntax of urban segregation*", published research paper, Bartlett School of Graduate Studies, UCL, London.

- **Axiality (Axial space or linear space).**

  Or linear representations; it was popularized by Bill Hillier at UCL, it is captured by drawing the longest and fewest axes of sight and movement that cover a layout making all possible connections (axial lines). It is the straight sight line for the possible bath to the targeted space from the base point. The length and density of axial lines will indicate how much information the building offers, how well the various parts of the building are linked with each other, how easily visitors will find their way around and access the gallery spaces. It also called Axial map,as shown in figure (3.30); as it is the longest and fewest lines used to cover the system. It is useful for the analysis of pedestrian movement patterns and activities in one dimension[1], and to present a concise description of architectural space.

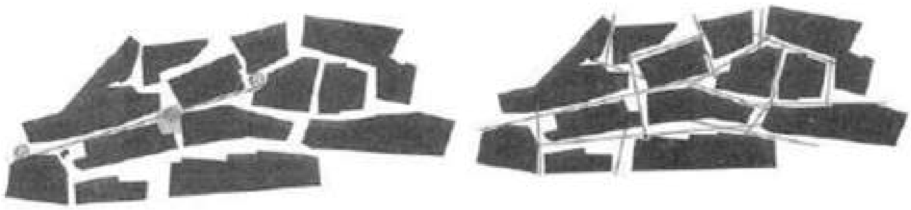


Figure 3.30 Axial line and axial map.
Source: - Mohammed, A. A, "*Spatial Conditions For Sustainable Communities: The Case of Informal Settlements in GCR*".

- **Convexity (Convex space).**

  Or convex maps; it was popularized by John Peponis and his collaborators at Georgia Tech.Convex spaces are studied from the point of view of size, geometry, shape and density and other characteristics like the number of convex spaces covered by an axial line.it is the result of the spatial convexity analysis, where all points within the space polygon are visible from any point within the polygon, as shown in figure (3.31).

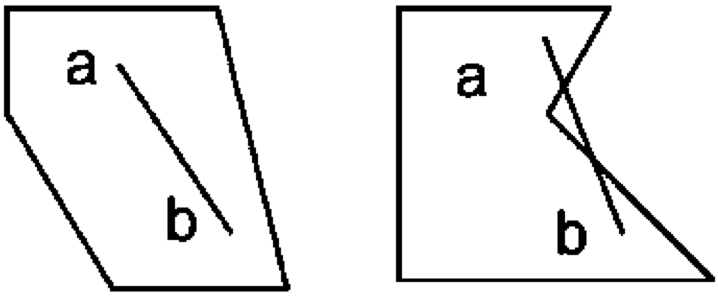


Figure 3.31 Convex space.
Source: - METAPHOR JV, "*GEM, Circulation and Wayfinding Schematic Design*".

- **Visibility (Isovist).**

  Visibility is partly captured by axial lines as these represent axes of sight and movement. However, axial lines do not represent the shape of vistas and views in a layout. For this reason we will use an analytic tool known as an (isovist).Isovist is the result of the convex map; it was popularized by Michael Benedikt at university of Texas, which is referring to the

[1]Mohammed, A. A, "*Spatial Conditions For Sustainable Communities: The Case of Informal Settlements in GCR*".

field of view from any particular point in the visual space polygon[(2)]. It is how far can the one see or move from one point to another in the space; so it was developed in landscape studies using GIS. Isovisit is used for examining complex patterns of human behavior. It could be generated using Depthmap software from Turner of Omnivista from Dalton, as shown in figure (3.32).

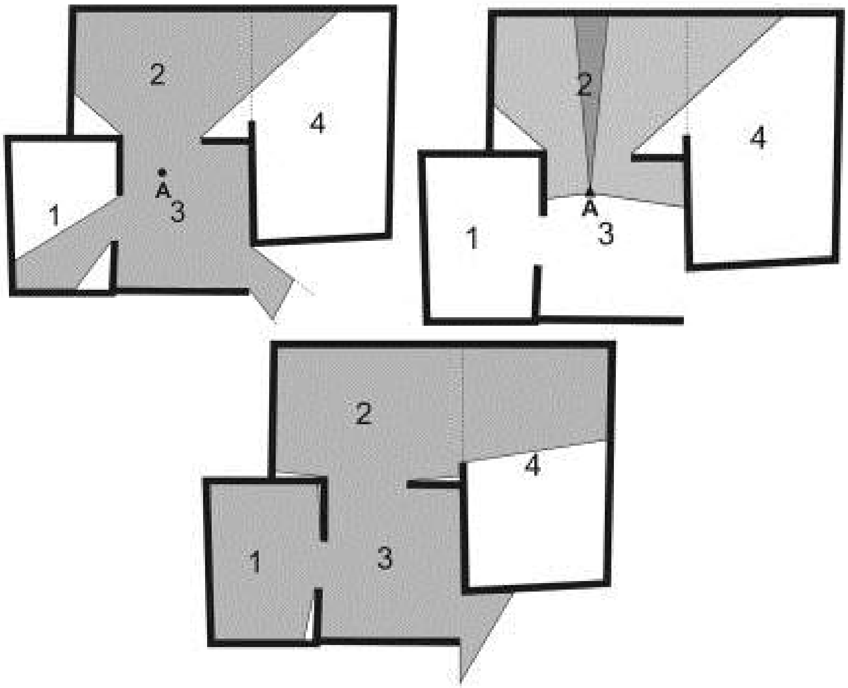


Figure 3.32 Isovist view space from a movable point A.
Source: - Kevin D. Fisher, "*Placing social interaction: An integrative approach to analyzing past built environments*".

- **<u>Space syntax analysis.</u>**

- **<u>Depth map</u>**

It is the topological distance; that space syntax measure[(1)]. Depthmap depends on the number of crossed lines; which represents the movement from space to another, when these lines are shallowness it means integration and when maximum it became segregation.

- **<u>Integration</u>**

It describes the degree to which an element like a convex space or an axial line is accessible by every other element in the building. It is the inverted value of depthmap; as it shows how to pass from one line to another in the axial map. It could be calculated by dividing the total depth by the number of spaces in the system (Integration α= 1/mean depth). It could be measured using drawn axial lines and choosing any line and study its mean depth related to other lines connected to it, as shown in figure (3.33). Each line in the axial map has an integration value differs from other lines; this integration value reflects the line importance

(2)Ibid, Mohammed, A. A.
(1)Batty. M, Rana. S, "*Reformulating space syntax: The automatic definition and generation of axial lines and axial maps*".

and how it is related to other lines in the map. The higher value refers to more integration; which make the line in the integration core with larger settlement. The integration core lines relates to all areas in the system and more closer to the highest integration line.

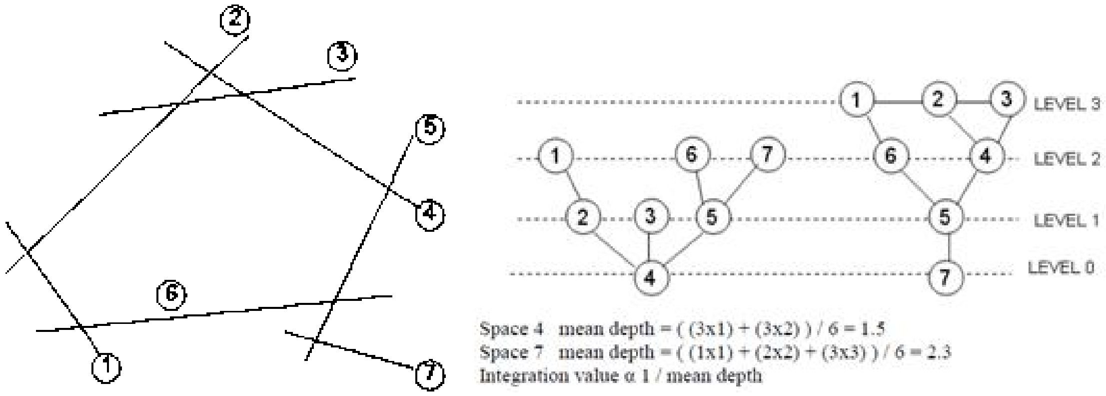


Figure 3.33 Integration value calculations.

Source: - Mohammed, A. A, "*Spatial Conditions For Sustainable Communities: The Case of Informal Settlements in GCR*".

Due to the relation between the spatial configuration and the human movement; the natural movement became the movement proportions on each line according to a specific attractor[(1)]. The movement pattern could be predictable by a survey for a certain area, counting the number of people moving (x person/min), and getting the integration value for each line in the axial map for this area. The movement pattern mostly has some spaces or lines have lower number of visitors and vice versa; which depends on the importance degree of functions allocated at each space, that what called Multiplier Effect[(2)]. Maps creation and analysis are applied through some computer programs such as Axman software, and Depthmap, as shown in figures (3.34) & (3.35).

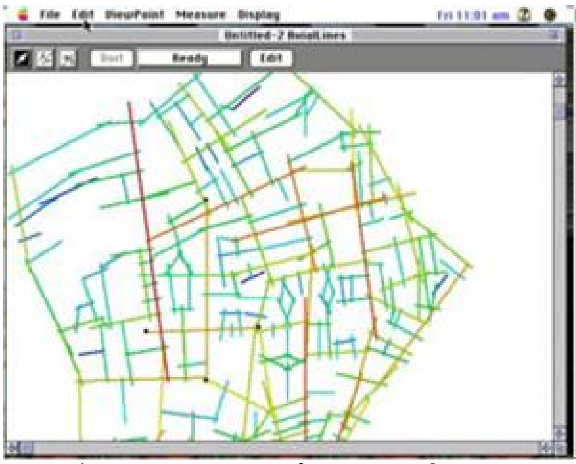


Figure 3.34 Axman software snap shot.

Source: - "*UCL SPACE SYNTAX SOFTWARE MANUALS, AXMAN, ORANGEBOX, NETBOX, NEWWAVE, PESH and SPACEBOX*", THE BUNDLE, July 2004.

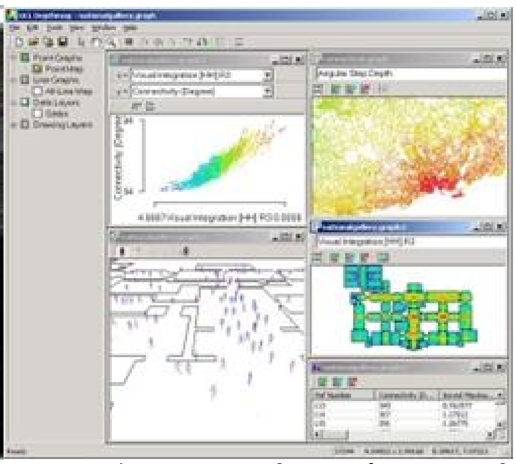


Figure 3.35 Depthmap software snap shot.

Source: - **http://www.spacesyntax.net/software/ucl-depthmap/**

[(1)]Ibid, Hillier. B, P (138 - 165).
[(2)]Ibid, Hillier. B, P (139 – 144).

- **Architectural application.**

Space syntax has become one of the analytical methods to study the interaction between human and spaces. Studying the movement pattern is more effective in the design process for predicting the movement circulation inside spaces. In the urban design space syntax provides the designer with more details about the relation between the centers and the surrounded areas and how it could work as a magnet for attracting more users.

Although it is widely used since few decades to perform visibility analysis of architectural and urban systems, but it can't provide the designer with more information about the visual quality as it ignores the superficial appearance of the surrounding environment such as surfaces texture, or colors, even about the urban layout property[1]. Space syntax also is measuring the distance between spaces topologically, and ignoring the metric distance. Beside that space syntax is not enough for understanding the social behavior as it can't provide any information about the user's decision making[2].

3.5.3. Algorithms written for certain purposes.

A. Spiraling

Spiral form looks like what could be seen in the stars and planets, or the sand storms. Its form was inherent from the plant growth patterns; which allow maximum number of petals to grow up in narrow spaces, or from the Ferro-liquid droplets tests;that show magnetic energy naturally distributing itself into a spiral manifestation[1]. The spiraling algorithm works as the small electron when it spins around atom nucleus, as shown in figure (3.36).

Figure 3.36 Spiraling Algorithm.
Source: - Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (13).

Using a series of points on a circle with a constant angle it forms a spiral lattice. The use of this spiral lattice in three dimensional forms produces an endless structured envelope from the same set of points placed in the original lattice, as shown in figure (3.37).

[1]Ratti. C, "*Space Syntax: some inconsistencies, Environment and Planning B: Planning & Design*".
[2]Hillier. B, Al. P, Ratti. C, "*Environment and Planning B: Planning & Design*".
[1]Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (10 – 21).

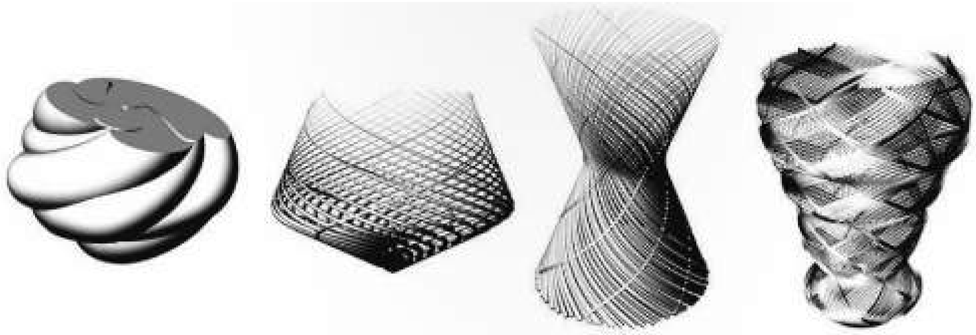


Figure 3.37 Spiraling Algorithm forms for a set of points.
Source: - Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (14).

B. Cracking

Cracking algorithm is mainly about how to divide a certain object into smaller particles using cracking as a method. The generated shapes are similar to the producer's shapes. The algorithm is made to recall shapes from a specific known origin[(1)], as shown in figures (3.38) & (3.39).

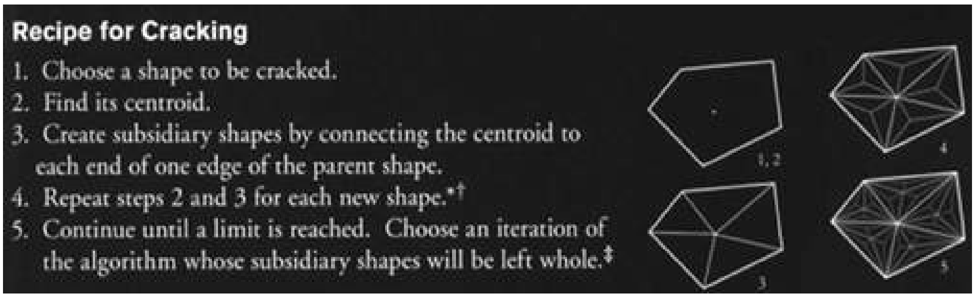


Figure 3.38 Cracking formations.
Source: - Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (52).

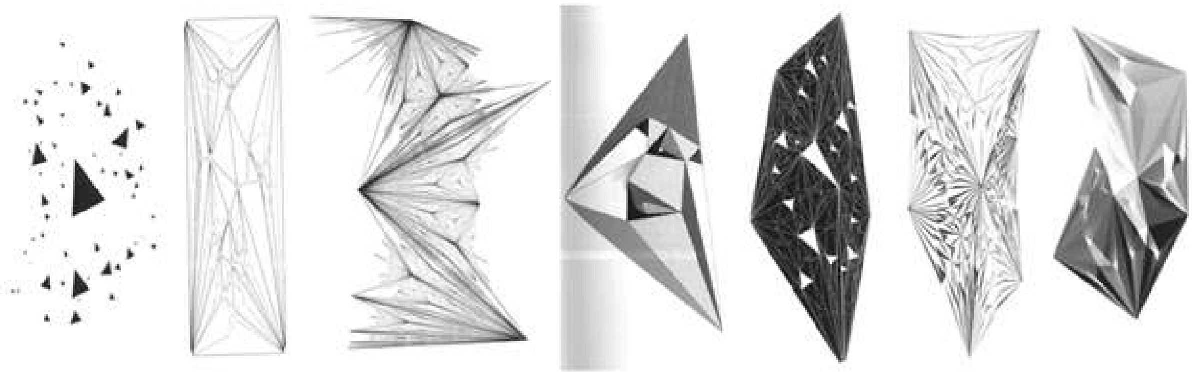


Figure 3.39 Cracking formations simple.
Source: - Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (52).

[(1)]Ibid, Aranda. B, Lasch. C, P (52 – 61).

C. Packing

Packing algorithm depends on the placement of any object according to certain rules controlling the relation between its neighbors, not place too close, no overlapping[1].It's a self-organized structuring in cells and as a behavioral trop in crowds[2]. Packing algorithm also provides many rich solutions for three dimensional design and material strategies, as shown in figures (3.40) & (3.41).

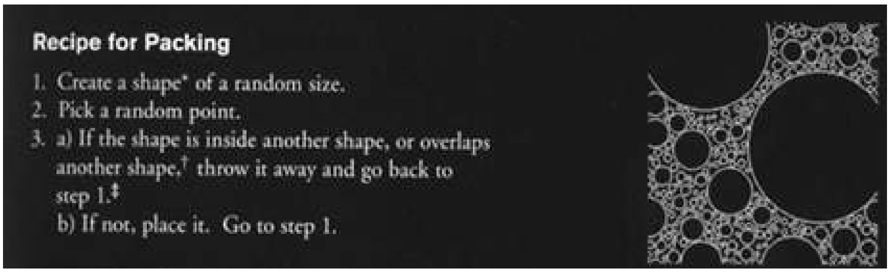


Figure 3.40 Packing algorithm.
Source: - Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (22).

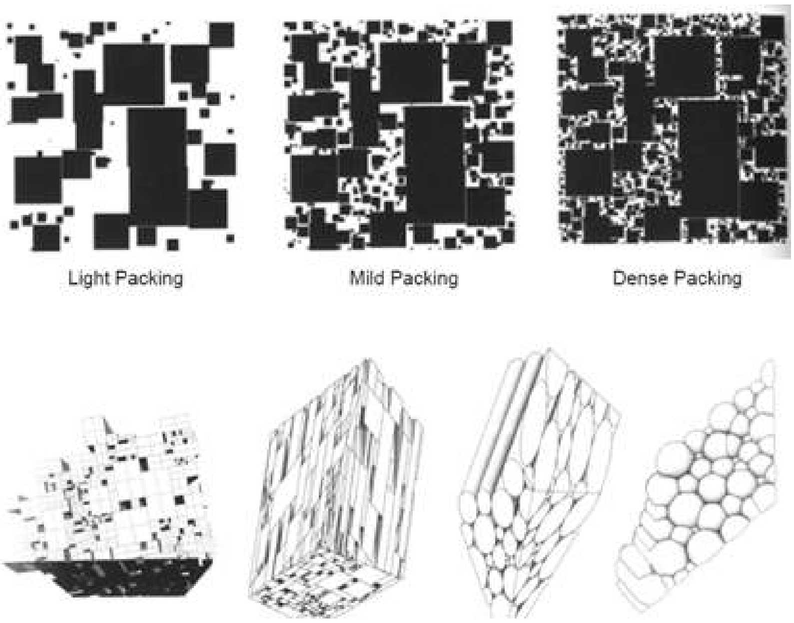


Figure 3.41 Packing algorithm in 2d & 3d.
Source: - Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", P (22).

[1]Ibid,Aranda. B, Lasch. C, P (22 – 31).
[2]El Daly. H. M, "*Revisiting algorithms in architectural design: towards new computational methods*", P(115 – 120).

3.6. Architectural design by Algorithms.

Modern time Architecture is characterized by its ability to take advantage of the innovations offered by science and technology. The relationship between new technology and new architecture forms are a fundamental datum of what is referred to as avant-garde architecture(1).Algorithmic application in architecture is considered to be an extension to the significant role of Algebra which is the third constituent of Mathematics in architecture design(2); that changed architect's contemplation in their design problems. The algorithmic architectural solution changed the upcoming architectural character of the new millennium; as a result to the advancement in scientific theories and the new concepts of the architectural context as a generative methodology, that made the architecture has no limits.

The architectural design is consisting of four main aspects; thatarchitectscare about them, as shown in table (3.1)(3):

Table 3.1 The four main aspects the architects are cared about.

Aspects	Explanation
•Function	It means how any building could deliver its message; it depends on crating good relationship between each zone inside the building with respect to the expected activities to be done inside it and the people who are going to use it. People movement inside any building, mainly depends on their performance, social characteristics, and if they are moving in groups or individuals.
•Form	It means how to form space; the project character, accessibility, orientation, structure system, lighting systems, the relation between the building and site conditions, future extensions, its environmental effects and the climatic changes impact on its spaces.
•Economy	The initial project cost, the construction cost, and project operating cost control.
•Time	The project adaptation with new technologies, and the ability for future extension.

Algorithms play a significant role over many of the project design stages (Conceptual design - Developed design stage – Detailed design and construction stage). The application of algorithms in the architectural design could be viewedin the main automated design applicationexplained as follows(4):

(1)Kolarevic. B, "*Designing and Manufacturing Architecture in the Digital Age*".
(2)Burry. J & M, "*The new Mathematics of Architecture*", P (9).
(3)Penna, William & others, "*Problem seeking, an architectural programing primer*", P (36).
(4)From:-
- Ibid, El Daly, H. M, P (195 – 196).
- Lim, Chor-Kheng, "*A Revolution of the Design Process*".

3.6.1. Generation Application [(1)].

In this application; the architect will be able to study the project outlines (zoning, relations, orientation, simple plan…etc.) before designing, byselecting any of the algorithms will be operated in this stage, and how it could be applied (separately or grouped) is depending on the type of the project.

A. Algorithms used for generating functional plan (By the Architect).

It will be the **first step** in the project design; that will generate the project zoning then simple plan. This step is very common in complex projects such as (mega complexes, hospitals…etc.). At the first; the architect should determine the following:

- Project type.
- Type of activities.
- Groups of people.
- Entrances & Exits.
- Services.
- Spaces relation matrix.

Next; an **Interactive Genetic Algorithm** will be operated to generate varies zoning alternatives. After that; an **Interactive Genetic Algorithm** will be operated for each zone to generate varies plans for each one. Then; checking if the generated zonings achieving the inputted rules, and select the most suitable alternatives. At the end; the architect will have a large number of zoning alternatives, or go back for checking the alternatives and rules.

After operating the previous algorithm steps; the final zoning of the project, relationships between zones with suitable areas, and the relationships between spaces included in each zone are generated as a base for the next stage of the design to get simple plan.

The **second step**for generating a functional plan; is to use the previously generated zoning and start creating spaces inside plan. This step will be done using the same algorithm used in the first step but to reach another goal and different rules. After operating the previous algorithm steps;an almost complete plan of the project with the best relationships, zoning and areas is generated.

B. Algorithms used for generating the form (Automated).

Sometimes architects start generating the form before the function and vice versa; so it might be the second step or the first step in the design process. Generating a significant form is always an important matter for any project to provide it with a special character; there for it is more important for the buildings that expresses arts and history such as (Museums, Art centers, Galleries…etc.). Before starting the form generator algorithm the architect should determine the following:

- The architectural design concept.
- The project character.
- Building environmental behavior.
- The previously generated plan.

After operating the previous steps;the main form of the project is generated with respect to the designer concept. The generated plans and forms are mainly depending on the project type even in functional plan's design or from generation.

---

(1) From:-

- Larsen, N.M, "*Generative Algorithmic Techniques for Architectural Design*".
- Milena, S &Ognen, M, "*Application of Generative Algorithms in Architectural Design*".

C. Examples for the Use of Generation.

Project:	***National swimming center (Water Cube), Beijing city, China.***
Designer:	CSCEC – CCDI – PTW & ARUP.
Generation:	Form generation – Packing & Voronoi diagram.

The concept combines the symbolism of the square in Chinese culture and the natural structure of soap bubbles translated into an architecture form to create an ecologically friendly, and energy saving building[(1)].This uniform crystaline packing was extracted from the space filling arrangement of similar cells by mathematics[(2)], as shown in figures (3.42) & (3.43).

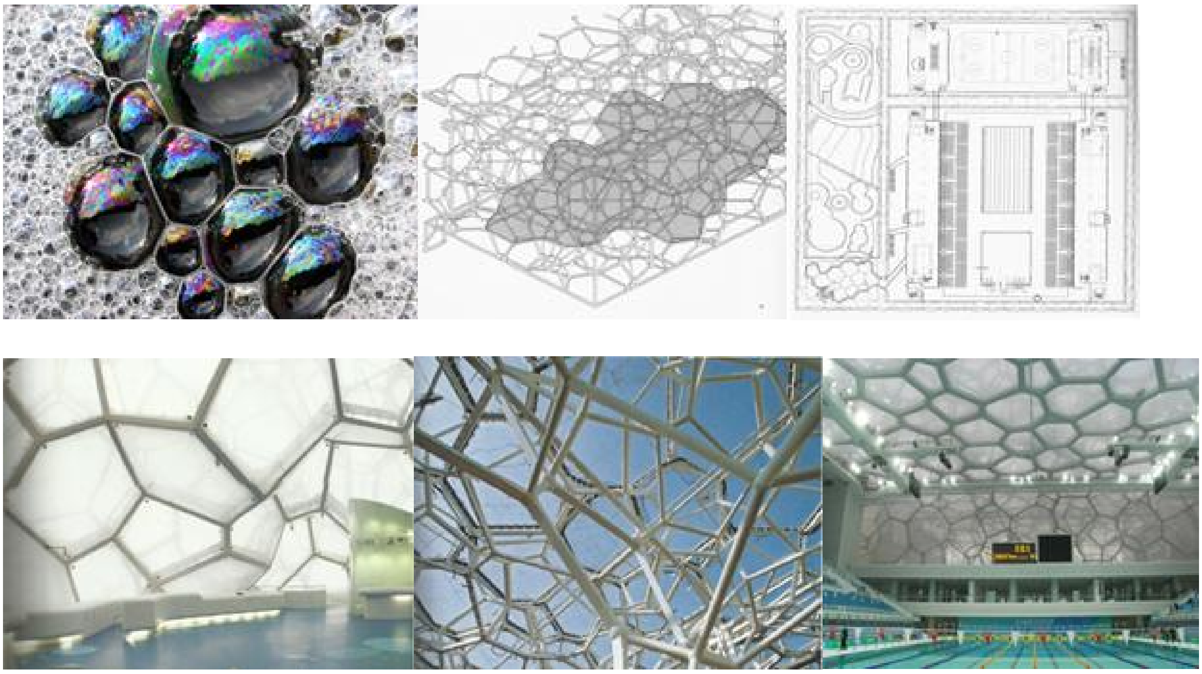


Figure 3.42 National swimming center (Water Cube) concept, plan & structure.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (87-91).

Figure 3.43 National swimming center (Water Cube) 3D & Ecological system.**Source:** www.ptw.com.au/ptw.php

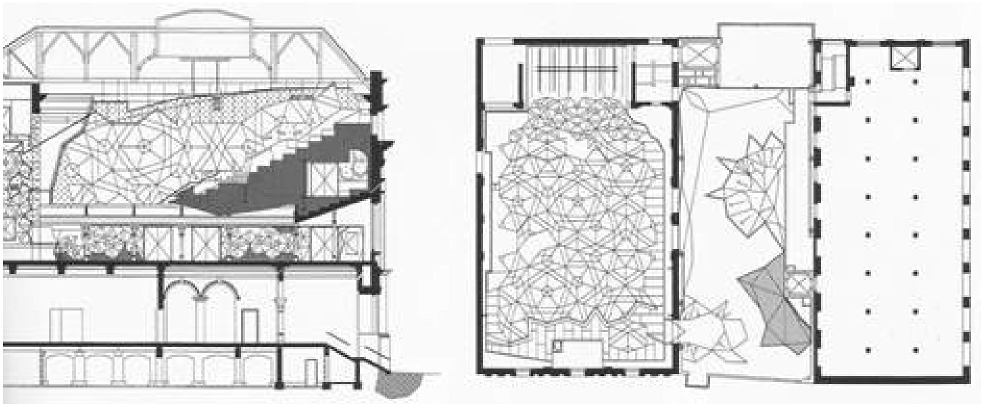
[(1)]http://www.ptw.com.au/ptw.php
[(2)]Ibid, Burry. J & M, P (87-91).

Project:	***Story Hall, Royal Melbourne Institute of Technology, Australia(1).***
Designer:	Ashton ReggattMcdougall.
Generation:	Form generation – Packing & Voronoi diagram.

The contemporary world view of form has been changed duo to the significant change in the concept of form generation. In the 19th century, this change was made after the Aperiodicity; which is the pattern that will never be repeated when extended infinitely.

The new façade of the hall was emphasized from blurring the historic façade. The used tilling method presents a new decorative language on the exterior textured verdigris; this mathematical tilling solution divided the plan into two simple tessellating diamond shaped forms, with a non-repetitive pattern produced by mistake to renew the Story Hall, as shown in figures (3.44), (3.45)& (3.46).

Figure 3.44 Story Hall form generation concept.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (104).



(1)**Story Hall: -** Is the oldest part of the Royal Melbourne Institute of Technology's Storey Hall actually dates back to 1884 when the Hibernian Hall was designed by Tappin Gilbert &Denneh for the Hibernian Australasian Catholic Benefit Society. The hall was constructed in 1887 and features Corinthian columns set on a high base of Malmsbury bluestone. On the first floor, elaborate temple windows in the Ionic order are positioned between stone columns. It was used by 19th century Catholics for social purposes and was hired out for private use. At the time of its completion, it was the second-largest hall in Victoria. The building ceased to be Hibernian Hall in 1903 and changed ownership several times. In 1957, the building was purchased by the Department of Education for the Royal Melbourne Technical College (as RMIT then was) and the building was cleared of rubbish and refurbished. The new building opened in 1959 as Storey Hall, named after Sir John Story, an RMIT council member for 15 years.

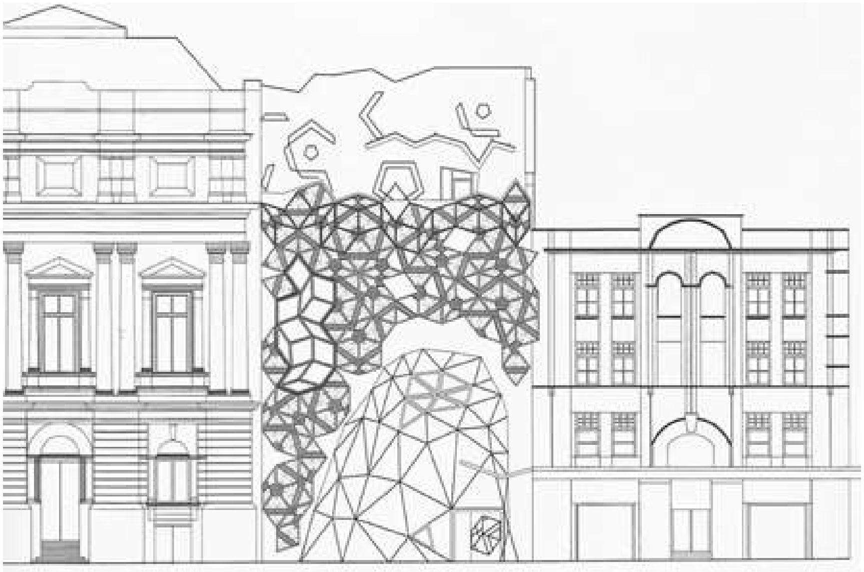


Figure 3.45 Story Hall (plan, section & elevation).
Source: Burry. J & M, "*The new Mathematics of Architecture*", P (105).

Figure 3.46 Story Hall, Royal Melbourne Institute of Technology interior & exterior views.
Source: www.adonline.id.au/buildings/storey-hall/

3.6.2. Permutation Application.

Through using algorithms; the designer will be able to study, and evaluate the previously generated plans and form under more constraints. Permutation application is mainly caring about improving the design by generating other alternatives, by adding more conditions and rules related to function such as (movement patterns, security controls, evacuation…etc.). With regard to permutation role in the form; another rules are included for the algorithm such as (spaces hierarchy, orientation…etc.)[(1)(2)].

A. Algorithms used to modify generated plans (Automated).

In order to get a functional plan; the designer will run a different algorithm such as space syntax or A* algorithm with some new rules; in order to study the users circulation and movement.

B. Algorithms used to modify form (Automated).

Modifying form in Permutation stage could be applied using similar algorithm used in the Generation stage. This time the designer will use Voronoi algorithm on the previously generated form but with some changes in the point's location.

C. Algorithms used to make permutation in time and economy (Manually by the Architect).

As permutation is a modification tool during the project design stage; it could be also used to study the project expansibility using an **Interactive Genetic Algorithm**.

D. Examples for the Use of Permutation.

Project:	***Royal Academy of Arts, London, UK[(3)].***
Designer:	Hopkins Architects.
Generation:	Plan Permutaion – Space Syntax.

In order to improving visitor access in the Royal Academy of Arts;Hopkins Architects are assisted to develop and evaluate the design proposals to connect Burlington House (the home of the Royal Academy) to Burlington Gardens (the former Museum of Mankind). The problem was to anticipate the impact of the proposals on visitor access and circulation patterns.

Museums and art gallery buildings act socially and culturally to create and control the interface between visitors, staff and collections. The design of their spatial layout has a significant effect on how people find their way around and come into contact with each other and with the collections. The study was focusing on the "social atmosphere" between the two building depends on how the building encourages convenient wayfinding and informal browsing among visitors, as shown in figure (3.47). The study methodology was mainly consisting of the following:

- Spatial accessibility analysis.
- Observation study of current visitor activity patterns.
- Option testing to generate and evaluate design proposals.

---

(1) Duffy, D.E, and Quiroz, A. J, "*A Permutation Based Algorithm for Block Clustering*".
(2) Wu, J.C, and Wei, M. H, "*Design of an Optimal Benes WEX Architecture Based on Sufficient Permutations*".
(3) www.spacesyntax.com/project/royal-academy-of-arts/

- Design advice on ways to improve access and circulation.

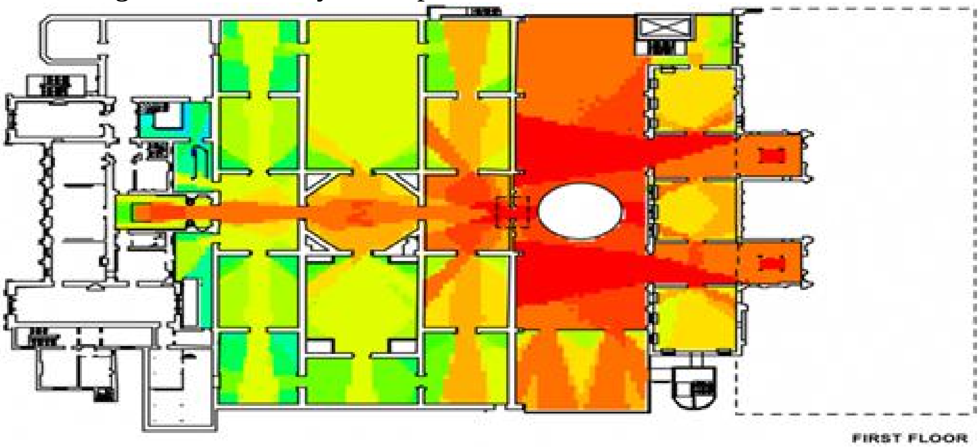


Figure 3.47 Royal Academy of Arts, space syntax
Source: - www.spacesyntax.com/project/royal-academy-of-arts/

3.6.3. Optimization Application.

Optimization application is describing the process of generating the best design solution for the project. It's a fully automated stage; when more restrictions added within the model, whether of the architectural, structural, natural and biological systems. Optimization is considered to be an architectural form-finding tool derived from the new families of Algorithm provided by the new automated system[(1)].

A. Algorithms used to study structure system for generated forms (Automated).

Structural optimization in architecture is mostly connected to Antoni Gaudi; as the best known architect to apply it in forming the arches and single columns of convent Santa Teresa and the hewn inclined columns of the Colonia Guell chapel. Structure economy also has become one of the optimization common applications in the field of architecture.

B. Algorithms used to study energy saving (Automated).

Using optimization process is a better way to cope with the race for reducing the energy emissions and consumptions of the build environment. It is connecting the environmental analysis for air flow, heat, light, and acoustical calculation with the architectural design; in order to get the best performance for the build environment. This type optimization could be applied mathematically in two approaches stochastic and deterministic. Stochastic approach combines random components and run under certain condition to get outcomes, and when the same process is repeated under the same conditions the outcomes might be different than the previously generated. In Deterministic approach, the values are assumed precisely and each operation generates an exact value to the next step.

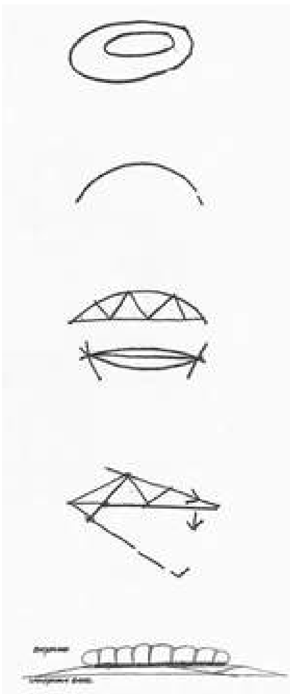
[(1)] From:
- Zitzler. E, "*Evolutionary Algorithms for Multi-objective Optimization: Methods and Applications*", P (19-69).
- Ibid, Burry.J & M, P (118).

C. Examples for the Use of Optimization.

Project:	***Melbourne Rectangular stadium, Melbourne, Australia.***
Designer:	COX Architects.
Generation:	Form optimization – Structure system.

The combination between environmental sustainability principles and effervescent sculptural qualities that evolved from functional and structural considerations is the main concept of Melbourne Rectangular stadium. The stadium has become a landmark on the Yarra river presents sports and entertainment. The roof design is taking the shape of dome inherent structural efficiency using light weight structure with steel framed geodesic bio frames.

The initial proposal is developed by architects and Arup engineers, using aesthetic and programmatic criteria to produce the detailed design. In order to find the optimal solution for the roof that perform structurally, light and esthetically at the same; a flexible geometrical model is merged with structure analysis with optimization routines to get an individual member's sizes for every piece of steel. First; steel members are assigned of ideal size, then; loads are updated for different weights, after that; a transformation process of information between the geometrical model and the structural analysis, that help the designer to choose between many forms. The effect of each form on the amount of steel and curvature shape could be observed easily in the optimization stage, as shown in figures (3.48), (3.49), (3.50)& (3.51).



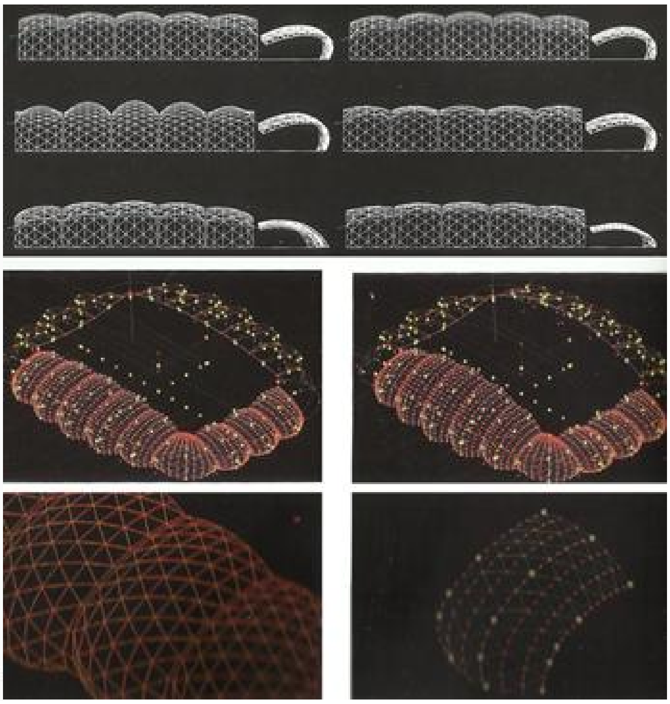


Figure 3.48 Melbourne stadium concept. **Figure 3.49** Melbourne stadium structure optimization.
Source: - Burry. J & M, "The new Mathematics of Architecture", P (134-136).

Figure 3.50 Melbourne stadium form.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (137).

Figure 3.51 Melbourne stadium interior and exterior.
Source: - Burry. J & M, "*The New Mathematics of Architecture*", P (135).

3.6.4. Simulations Application.

In order to check some items in the design such as (the interior environment quality, structure performance, evacuation availability…etc.); the designer has to run certain algorithm. Many types of algorithms may be applied to simulate the building performance, and the interactions between users and building componantes, including Swarm Intelligence, A* algorithm, and other algorithm created for certain purposes. In case the designer is intending to test the availability of people flocks to move inside the building; Swarm Intelligence algorithm will be helpful, as it can simulate the flockmate's behavior using animation techniques, based on an written algorithms[(1)]. This algorithm is solving the problem of moving groups of people to any direction. It could be applied in the normal cases for public buildings and also for evacuation in case of emergencies.

A. Examples for the Use of Simulation.

Project:	***Al Raha Development, Abu Dhabi, UAE.***
Designer:	Foster & Partners.
Generation:	Simulation – Environment impact.

A new architectural icon constructed in Abu Dhabi is a mixed use water front development. Unusual shape taking into account the site conditions and the environmental constrains, as shown in figures (3.52) & (3.53). The design concept was based on translating the interaction between built fabric with sun and wind into numerical analysis. This analysis was made using two types of models; the first model was a parametrically described one that morph according to feedback on its performance when influenced by some psychotropic, as shown in figures (3.46), the second model was presenting the deformation occurred on it according to the different environmental variations such as (the effect of air flow, changes in temperature degrees…etc.), as shown in figures (3.54) & (3.55). The project was driven by environmental considerations presented in the dynamic equilibrium between aesthetic and optimization.

Figure 3.52 Al Raha Development exterior view.
Source:www.fosterandpartners.com/projects/al-raha-beach-development/

(1) Buus, D.P, "*Constructing Human-Like Architecture with Swarm Intelligence*",P (13-55).

Figure 3.53 Al Raha Development interior views**.**
Source: - www.fosterandpartners.com/projects/al-raha-beach-development/

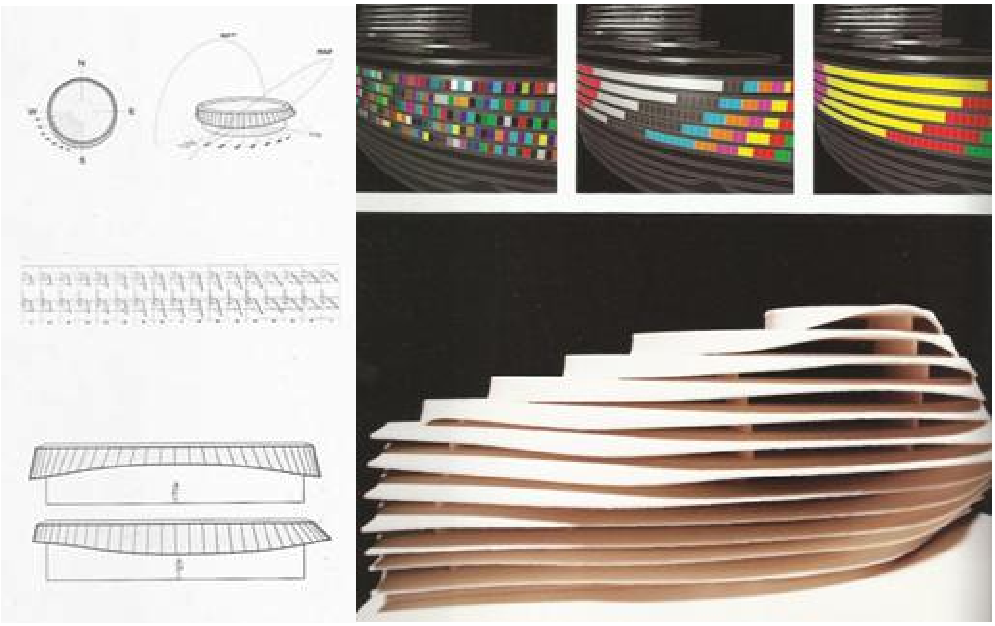


Figure 3.54parametrically described model.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (148-150).

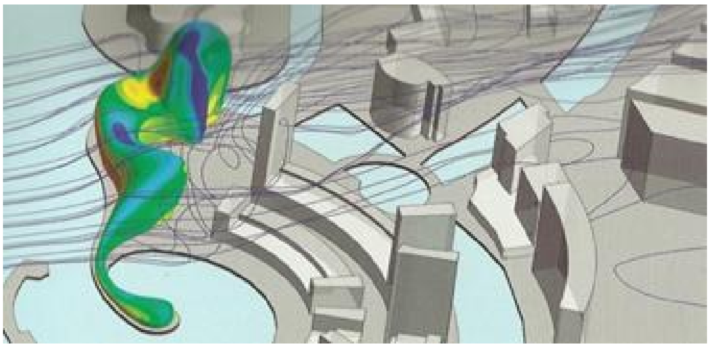


Figure 3.55 Air flow.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (151).

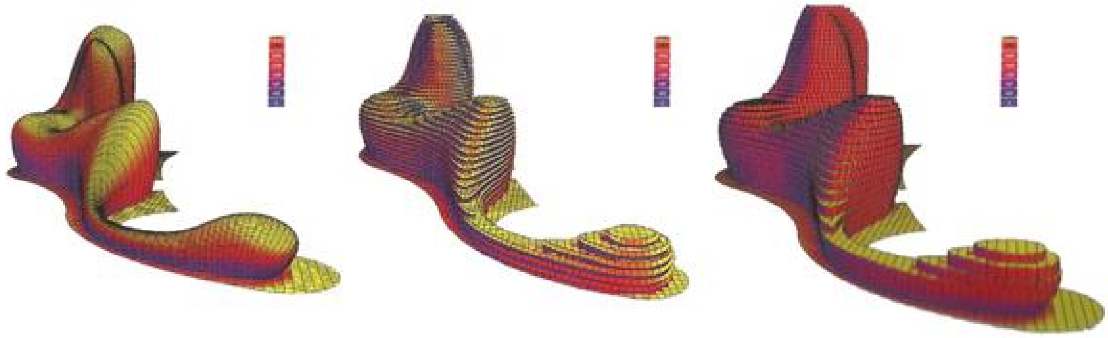


Figure 3.56 Environmental changes affection on the model.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (151).

3.6.5. Transformation Application[1].

It is a dependent application; as it is applied after the Simulation application. Transformation is the modifications applied on the design in order to improve its performance. It is a new kind of mechanical control of building items according to climatic changes, the needed amount of light…etc. Algorithms created for certain purposes are mainly used in this stage; sometimes it could be combined with those algorithms used in Generation and Permutation applications. Choosing which algorithm to use is depending on the type of the project itself (e.g. Hospitals and hotels design could be reached through a full algorithm starts from achieving the best functional relations of the form and the indoor environmental quality, but it is a very complicated algorithm to achieve). On the other hand it is totally different in designing a pavilion or a museum; the main concern in these building is how to get the most impressive form in addition to the most suitable structure and relations, accordingly algorithms used in Generation and Permutation will be applied.

A. Examples for the Use of Transformation.

Project:	***The Pinnacle, London, UK.***
Designer:	Kohn Pedersen Fox.
Generation:	Form Transformation – Environmental impact.

The building is presenting the combination of simple geometries and sculptural form as a part of the pre- rationalization stage of the design. The design was focusing on the environmentally, structurally performance, construction simplicity and maximum return of investment in GIFA[2]. In order to reduce the build area; simple plan is made of two circular areas resulted from rounding the acute angles of the triangular plan by 2.5° repeated and connected in the elevation by a tangential lines, as shown in figures (3.57) & (3.58). The building façade is consisting of two panel frames both of them are rectangular frames; the first is internal panel which includes opening windows, and the second one is the external panel that looks like snakeskin pattern; that provides weather proofing and natural ventilation.

[1] Ibid, El Daly, H. M, P (183-189).
[2]**GIFA: -** Gross internal floor area.

Three systems were adopted in the design stage to transform the main shape of the building according to some constrains, as shown in figure (3.59). The first method was packing the external panels with small openings, the second method was placing the constant distance between the two panel frames by a constant angle to avoid collide between them that provided the plan with more GIFA, and the third system was studying the position of each opening in the external panels and its distance from the internal panel, as shown in figure (3.60).

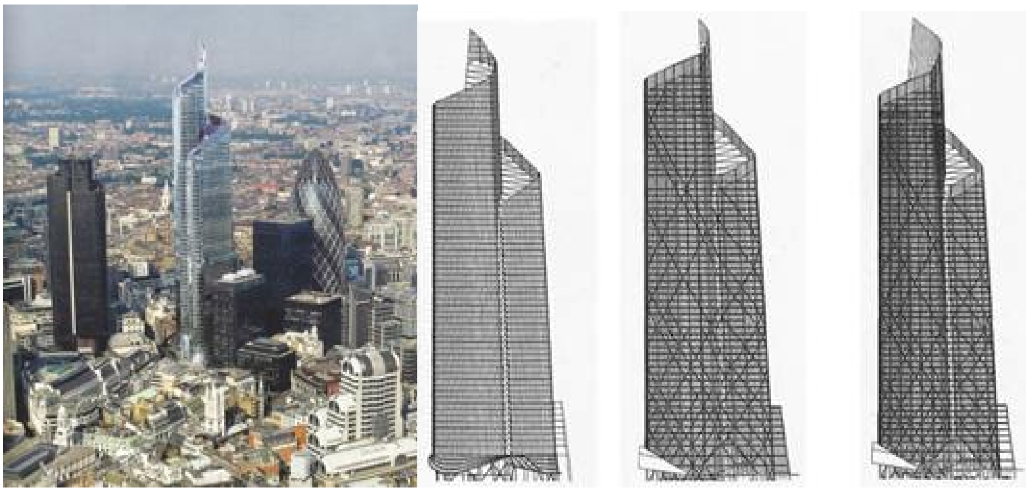


Figure 3.57a.The Pinnacle building b. The Pinnacle form changes.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (142-143).

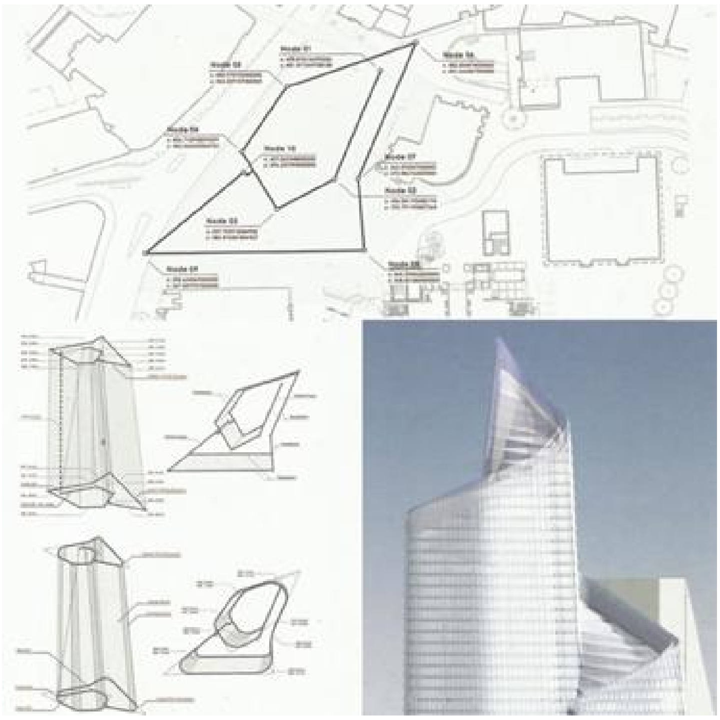


Figure 3.58 Implementation on site and base changes.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (145).

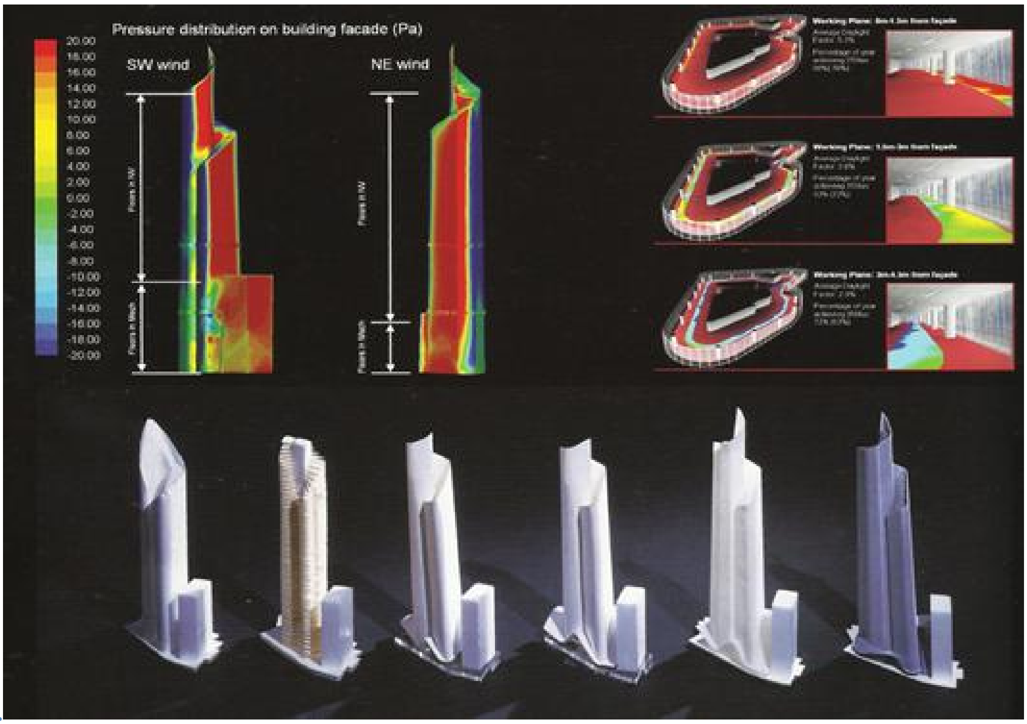
).

Figure 3.59 Wind effects and model form stages.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (144).

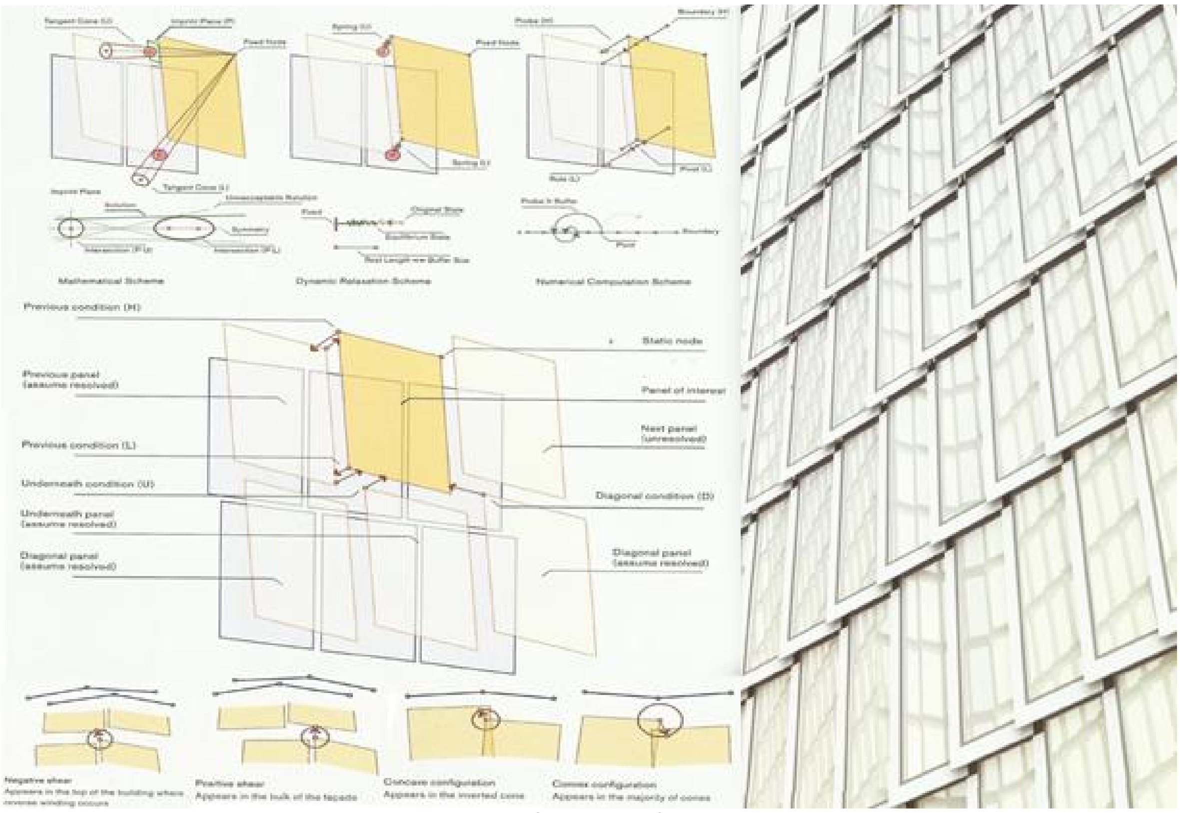


Figure 3.60 Transformation of window panels.
Source: - Burry. J & M, "*The new Mathematics of Architecture*", P (145-146).

3.7. Conclusion.

This chapter was mainly discussingAlgorithmic form generation and design solutions, by presenting ahistorical background about algorithms,and its different difinitions. After that, a discribtion for how algorithms could be expressed was mentioned.Latterly, an explanation was presented for the types of algorithms applied in the field of architectural design (commonly applied algorithms – analytical methods based on algorithms – algorithms written for certain purposes), as concluded in table (3.2).

Table 3.2 Algorithms used in the Architectural designfield[(1)].

Commonly used algorithms	Analytical methods built by algorithms	Algorithms for certain purposes
Voronoi algorithm.	Space syntax.	Spiraling.
Cellular automata.		Cracking.
Swarm intelligence.		Packing.
Genetic algorithm		
Stochastic search.		
A* algorithm.		

Finally, more clarification for theautomatedarchitectural design stages using algorithmswas introduced, as concluded in table (3.3), and supported with some examples for different types of buildings, which algorithms were used in during the design process.

Table 3.3 Automated Design stages using Algorithms[(2)].

Application	Field of application	Used algorithm
• **Generation**	Create forms, plans, and layouts depending on a certain concept from scratch.	• Cellular Automata. • Voronoi tessellation. • L-system. • Other algorithms such as (packing, cracking, tiling…etc.). • Algorithms created for a certain purposes such as (interactive genetic algorithm).
• **Permutation**	To study generated design alternatives depending on certain roles.	• Interactive genetic algorithm. • Voronoi diagram.
• **Optimization**	Improving the design to achieve certain values.	• Stochastic search. • Genetic algorithm.

[(1)]Done by researcher.
[(2)]Done by researcher.

• **Simulation**	Simulating the generated design in order to see if certain requirements are achieved.	• Swarm intelligence. • Space syntax. • A* algorithm. • Algorithms created for a certain purposes.
• **Transformation**	Make some changes on the generated design to achieve certain requirements.	• Algorithms created for a certain purposes. • Other algorithms such as algorithms used in Permutation and Generation.

The use of mathematics especially algorithm in the field of architecture emphasized new type of forms, consequently, new design solutions were generated due to this impact, which could be observed especially in public buildings design, such as museums. In the next chapter; an explanation will be introduced for how could algorithms affect the architectural design of museum buildings, in order to produce more enhanced and matured forms and design solutions.

Chapter 4: Architectural design of Museums using Algorithms.

4.1. Introduction.

Modern time Architecture is characterized by its ability to take advantage of the innovations offered by science and technology. The relationship between new technology and new architecture forms are a fundamental datum of what is referred to as avant-garde architecture(1).Algorithmic application in architecture is considered to be an extension to the significant role of Algebra which is the third constituent of Mathematics in architecture design(2); that changed architect's contemplation in their design problems. The algorithmic architectural solution changed the upcoming architectural character of the new millennium; as a result of the advancement in scientific theories and the new concepts of the architectural context as a generative methodology, that made the architecture has no limits.

In the design of Museum building, the architect is mainly caring about presenting an impressive form in combined with the museum function, based on a certain concept. In the term of function, there are three main aspects should be studied carefully including (the relation between the main zones in the museum – exhibition hall design – visitor's movement and behavior).

4.2. Designing Museums by Algorithms.

According to what had been discussed in the previous chapters,the Algorithms could be utilized in the field of architectural design of museum building as described in table (4.1).

Table 4.1 Utilizing Algorithms in the Museum design(3).

Museum component	Used Algorithms
Layout design (Urban circulation study)	• Voronoi tessellation. • Cellular Automata. • Swarm intelligence. • Genetic Algorithm. • Other algorithms such as (packing, cracking, tiling, fractal…etc.). • Algorithms created for a certain purpose, such as (interactive genetic algorithm).
Museum Plan (Spaces & zoning)	• Voronoi tessellation. • Cellular Automata. • Algorithms created for a certain purpose.
Movement circulation	• Swarm intelligence. • Space syntax. • A* algorithm. • Algorithms created for a certain purpose.

(1)Kolarevic.B, "*Designing and Manufacturing Architecture in the Digital Age*", University of Pennsylvania, USA.
(2)Burry.J & M, "*The new Mathematics of Architecture*", Thames & Hudson Ltd, 2012, P (9).
(3)Done by the researcher.

Exhibits arrangement	• Voronoi tessellation. • Cellular Automata. • Stochastic search. • Genetic Algorithm. • Algorithms created for a certain purpose, such as (interactive genetic algorithm).
Roofs design	• Voronoi tessellation. • Cellular Automata. • Stochastic search. • Algorithms created for a certain purpose.
Natural lighting & artificial light	• Cellular Automata. • Stochastic search. • Genetic Algorithm. • Algorithms created for a certain purpose.
Form & elevations	• Voronoi tessellation. • Cellular Automata. • Stochastic search. • Genetic Algorithm.

Based on the application of algorithms in the architectural design discussed in the previous chapter; in the architectural design of museums, the algorithmic applications could be used separately or altogether. Consequently, in order to produce a full architectural design of a museum digitally, the algorithmic design methodology will be followed, which depends mainly on some design stages that generates an in finite number of solutions to be studied in close, and evaluated, until an appropriate design solution is reached, as follows:

4.2.1. In the Generation stage[(1)].

In this stage; objects are generated using algorithms in this type ofdesign and their output are used for the further stages of design. Based on a certain design concept, museum plan and form could be generated as follows:

A. Designing the museum plan from scratch, starting with generating a full zoning plan, contains the most important relations between spaces, by applying the **Interactive genetic algorithm**[(2)], by certain steps, as shown in figure (4.1).

---

(1) From:-
- Ibid, Larsen, N.M, P (49-60).
- Ibid, Milena, S &Ognen, M, P (2-4).
- Khabazi, Z., "*Generative Algorithms using Grasshopper*", P (2-4).
- Ibid, Kotnik, T., P (60-89).
- Ibid, Tzortzi. K, P (65-103).
- Ibid, El Daly, H. M, P (211 – 225).

(2) Bentley, P, "*Evolutionary Design by Computers"*, P (1-20).

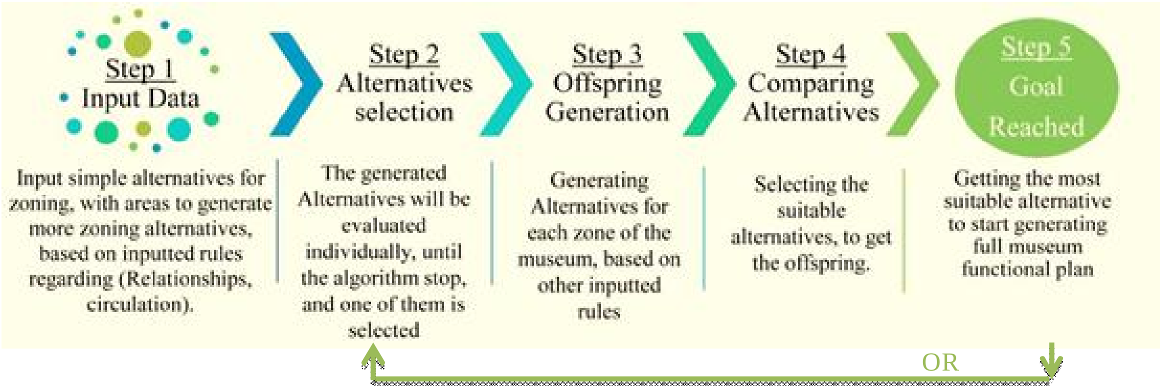


Figure 4.1 Generating Museum plan from scratch.

Source: Done by the Researcher.

B. Generating museum form as a start of getting the final form, the architect can use the form generating algorithms such as **Voronoi algorithm, Fractals, Packing, and Cracking**, according to certain steps,as shown in figure (4.2).

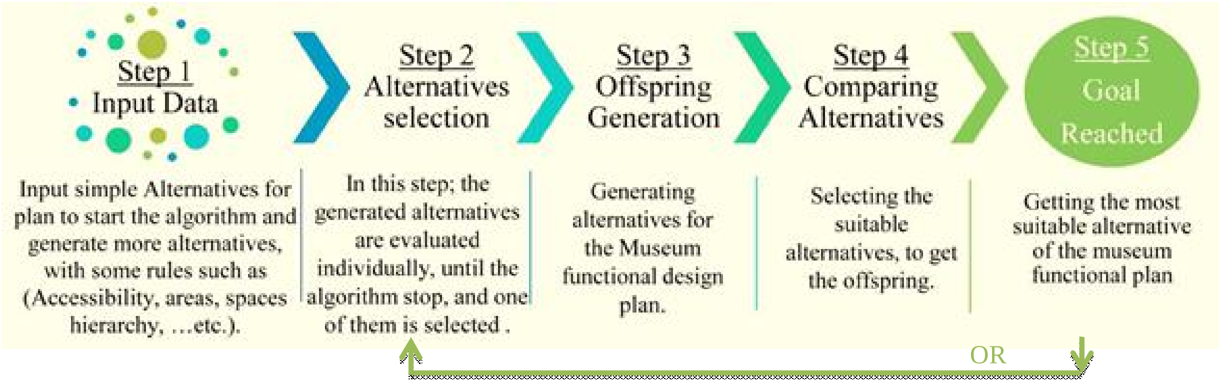


Figure 4.2 Generating functional Museum plan.

Source: Done by the Researcher.

C. In order to generate a significant museum form, the architect has to specify the main design concept for the museum to be followed in the form generation stage. In this step, some algorithms will be operated such as **Voronoi Algorithm, Cellular Automata,Fractals, Packing, and Cracking**, according to steps explained in figure (4.3).

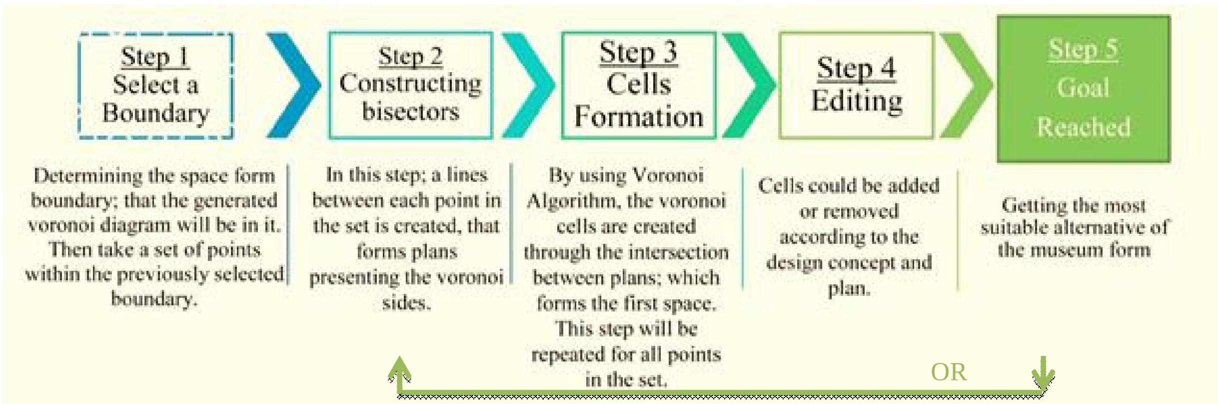


Figure 4.3 Generating Museum form.

Source: Done by the Researcher.

4.2.2. In the Permutation stage[(1)].

When the zoning stage is fully completed and a simple plan is generated; Permutation stage will be operated as follows:

A. At this stage, the designer starts to evaluate the resulted plan if it presents the best relations between spaces, and if the design is based on a clear movement pattern. This stage could be applied using **A* algorithm & Space Syntax**, as shown in figure (4.4).

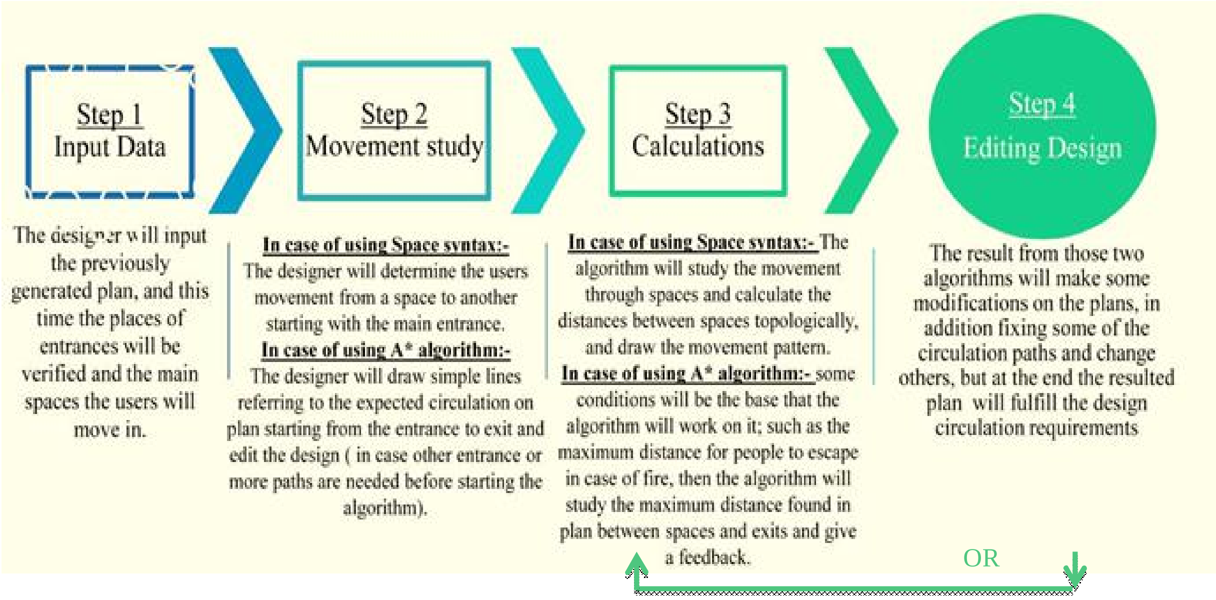


Figure 4.4 Movement study.
Source: Done by the Researcher.

B. Evaluating the form generated in the previous stage and applies other types of algorithms; in order to get the final form. This stage could be applied using **Voronoi diagrams**, and **Interactive genetic algorithms**.

4.2.3. In the Optimization stage[(2)].

Once the Generation and Permutation stages are completed; the designer will be able to get a full detailed plan with suitable form according to the design concept and space's relations. In the Optimization stage, the designer will have the ability to add more constraints in order to get the optimum design solution as follows:-

A. Museum functional plan, using **Voronoi, Fractal and Cellular Automata algorithms**.

B. An impressive form could be applied through choosing the most suitable structure system, using **Special Algorithms**.

---

(1) From:
- Ibid, Duffy, D.E, and Quiroz, A. J.
- Ibid, El Daly, H. M, P (225 – 234).

(2) From:
- Li.Li, "*The optimization of architectural shape based on Genetic Algorithm*".
- Ibid, El Daly, H. M, P (235 – 240).
- Ibid, Zitzler. E, P (50-107).

C. The best circulation paths, using **A* Algorithm and Space syntax**.
D. The most suitable indoor quality (air, lighting, temperature…etc.), using **Special Algorithms**.

4.2.4. In the Simulation stage[1].

In the simulation stage, the designer will be able to evaluate the generated design solution resulted from the previous stages, using digital simulation tools for the performance analysis. This test will include most of the Museum effective components, as follows:-

A. The exhibition design and the visitor's movement, using **Space syntax Algorithm,** as shown in figure (4.5).

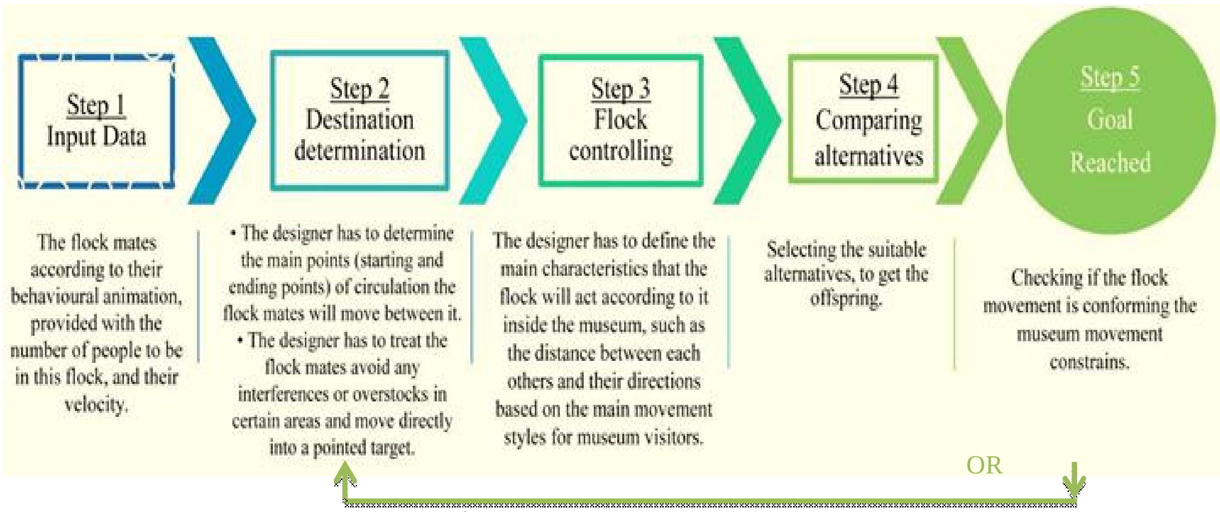


Figure 4.5 Visitor's movement.
Source: Done by the Researcher.

B. The effect of environmental changes on the indoor quality, **Special Algorithm & Genetic algorithm.**

4.2.5. In the Transformation stage[2].

At this stage the designer will be able to make some changes according to the results from the Simulation stage, in order to improve the museum design such as:-

A. Changing the exhibits location in order to facilitate the visitor's movement.
B. Adding more exits, helping visitors to evacuate easily in case of fire.
C. Choosing another system for lighting this affects the ability to see most of the exhibits.

---

[1] From:
- Ibid, El Daly, H. M, P (241 – 244).
- Ibid, Achten,H, and Joosen, G, "*The Digital Design Process: Reflections on a Single Design Case*".
- LIM, C.K, "*A Revolution of the Design Process*".

[2] Ibid, El Daly, H. M, P (245 – 247).

4.3. Case Studies for Museum designed by Algorithm.

4.3.1. The Grand Egyptian Museum (GEM), Cairo, Egypt.

Designer:	**Heneghan Peng Architects, ARUP, BuroHappold JV.**
Generation:	Form generation – Fractals. Plan Permutaion & Simulation – Space syntax.

The museum is led by the Egyptian Ministry of culture and sponsored by UNISCO, the design presented by the Architect Practice Heneghan Peng was chosen from an international competition in 2003. The museum it will be the home of 100,000 pieces of artifacts presenting the 7000 years of the ancient Egyptian history placed within the sight of the Giza pyramids. The museum design based on some constrains (the plateau edge – the view to the pyramids – Cairo-Alex approach). The museum has become an extension of the plateau edge (as the cliff); as the site is divided into higher and lower areas(1), as shown in figures (4.6), (4.7)& (4.8).

The concept was taken from the straight geometry of the pyramid itself and the adoption of the Sierpinski triangle shape. The design of walls based on the vast sloping translucent stone shaped by fractal patterning(2). These fractal shapes are placed on the elevation wall with a kind of hierarchy between different sizes of triangle panels, as shown in figures (4.9) & (4.10). The mega – steel frames for the panels are varying in their sizes and fabricated from steel members and pre-stressed cables on the triangular grid to support the onyx panels. The design of walls is based on allowing the visitors to see the pyramids view; through each gallery hall there is a sightline goes directly to the pyramids, as shown in figure (4.11).

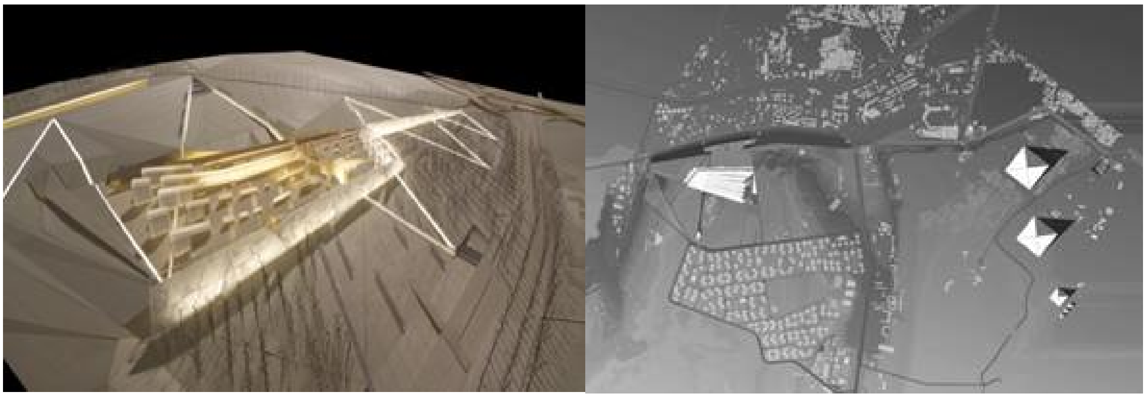


Figure 4.6GEM location and extended view to Giza pyramids.
Source: - www.hparc.com/work/the-grand-egyptian-museum/

(1) Peng, H and Archer, F, Arup AGU, unpublished project description.
(2)**Fractal patterning:-** It was described by Waclaw Sierpinski in 1915; which appeared also in the 13th century Italian art. It is called also Sierpinski sieve, gasket or triangle. It is a recursive subdivision of triangles by sub-triangles with the new vertices in the centre of each edge, in which one component triangle – the central one – is omitted in each generation or iteration (the holes in the sieve). This fractal shape could be produced by different ways computationally, and is a potentially infinite and scale less system.

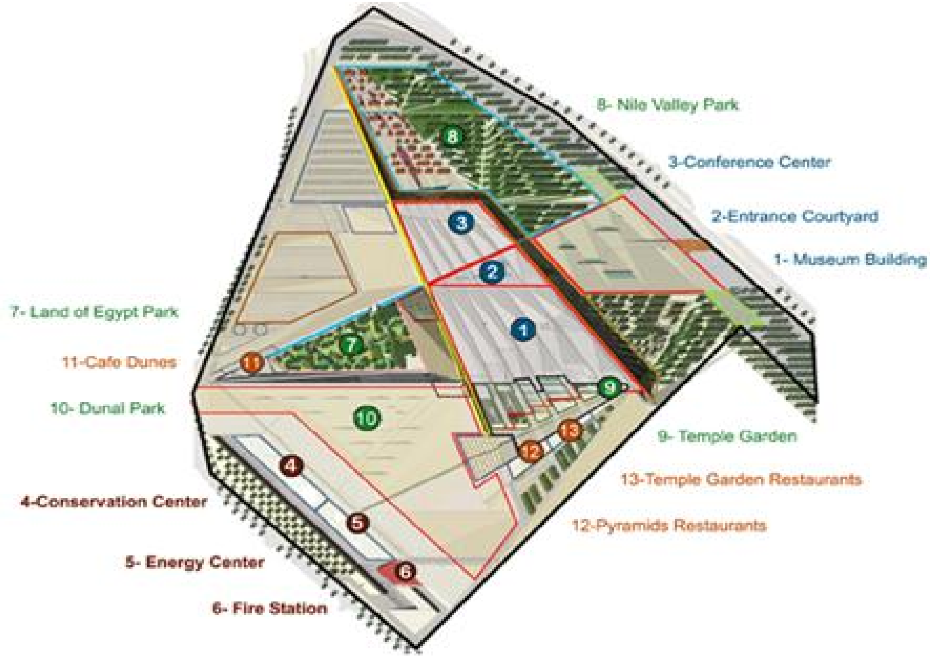


Figure 4.7GEM Zoning plan.
Source: - www.gem.gov.eg/

Figure 4.8GEM design divided into higher and lower areas.
Source: www.gem.gov.eg/

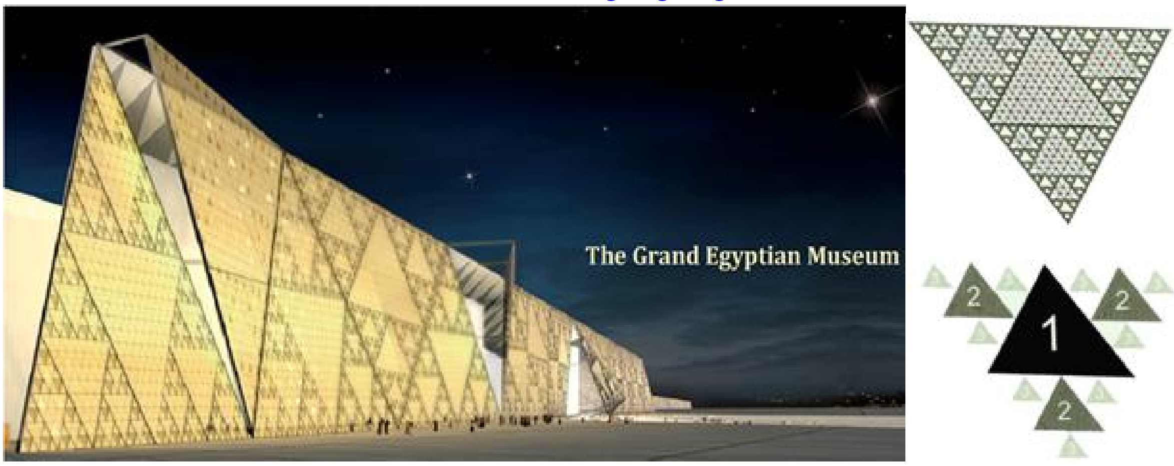


Figure 4.9 a. GEM main elevation. **b.** fractal arrangement on the elevation.
Source: www.gem.gov.eg/

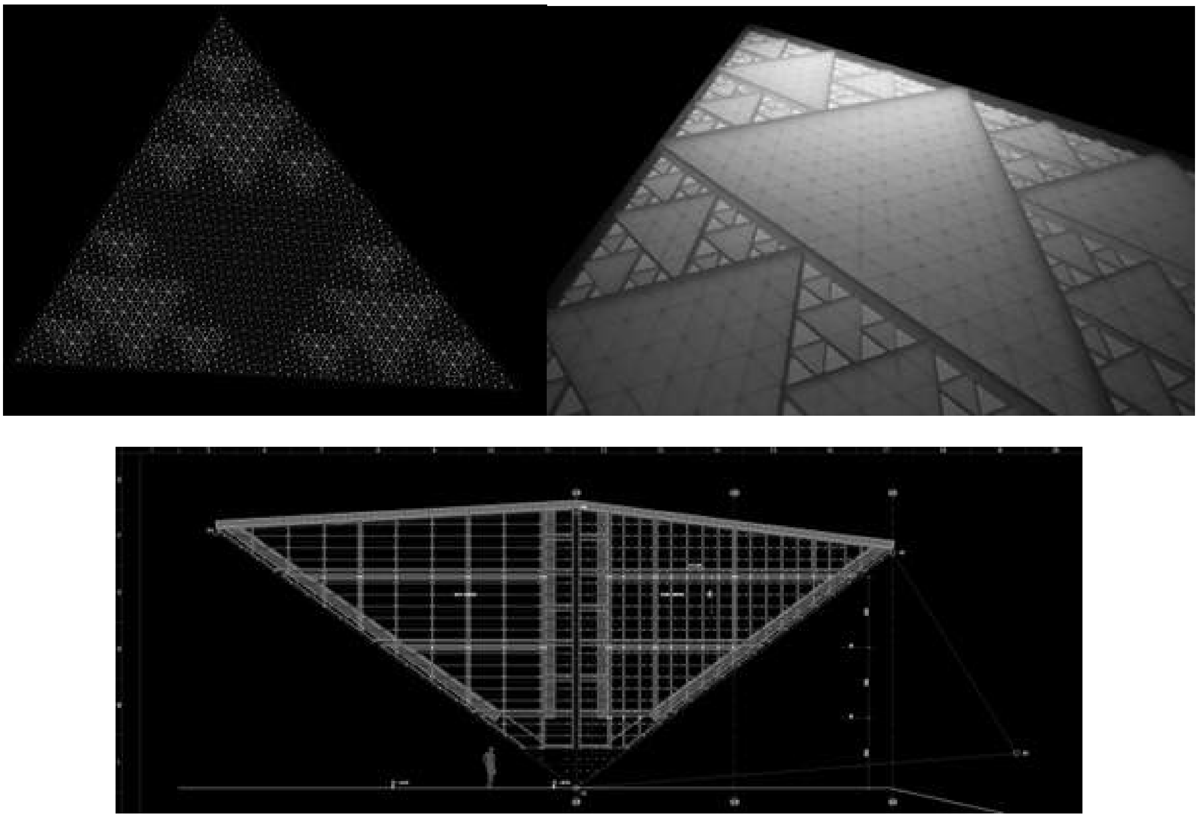


Figure 4.10 Façade design and the mega – steel frames for panels.
Source: www.hparc.com/work/the-grand-egyptian-museum/

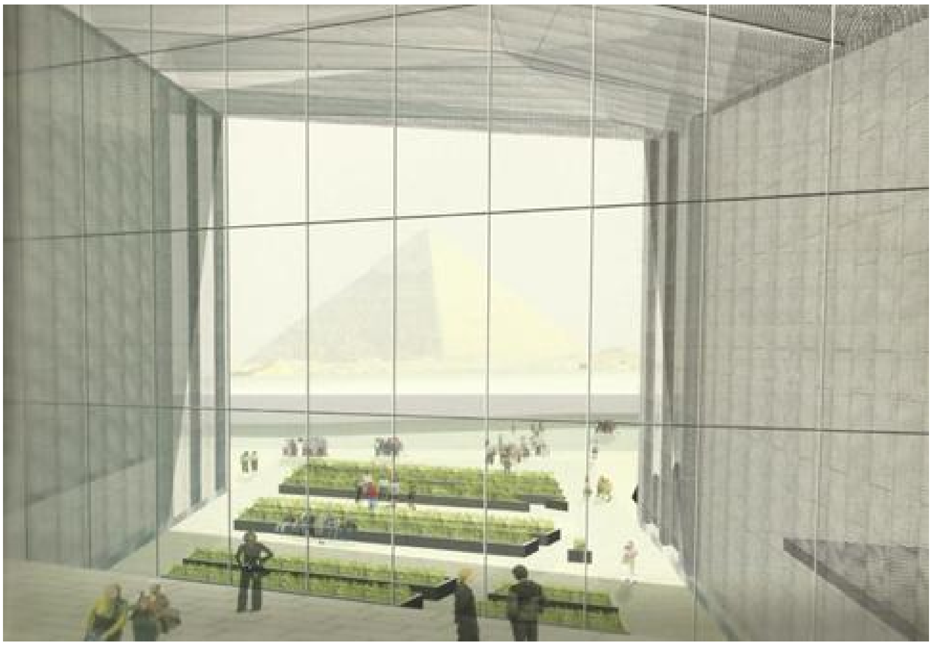


Figure 4.11GEM view of the pyramid.
Source: - Burry. J & M, "The New Mathematics of Architecture", P (97).

In order to evaluate the circulation visibility of museum layout, a study was made based on Space Syntax analytic techniques. The study was concerned mainly about the physical characteristics of the building, leading to achieve a good level of accessibility and interaction between visitors and artifacts, depending on the three main conceptual approaches (Axiality – Convexity – Visibility), as shown in figures (4.12), (4.13), & (4.14).

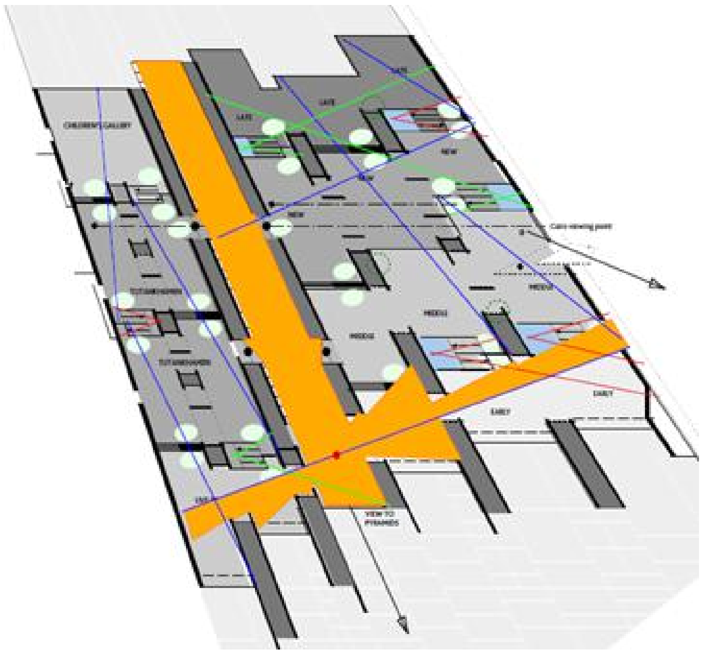


Figure 4.12 Axial lines capturing movement over ramps.
Source: METAPHOR JV, "*GEM, Circulation, and Way finding Schematic Design*".

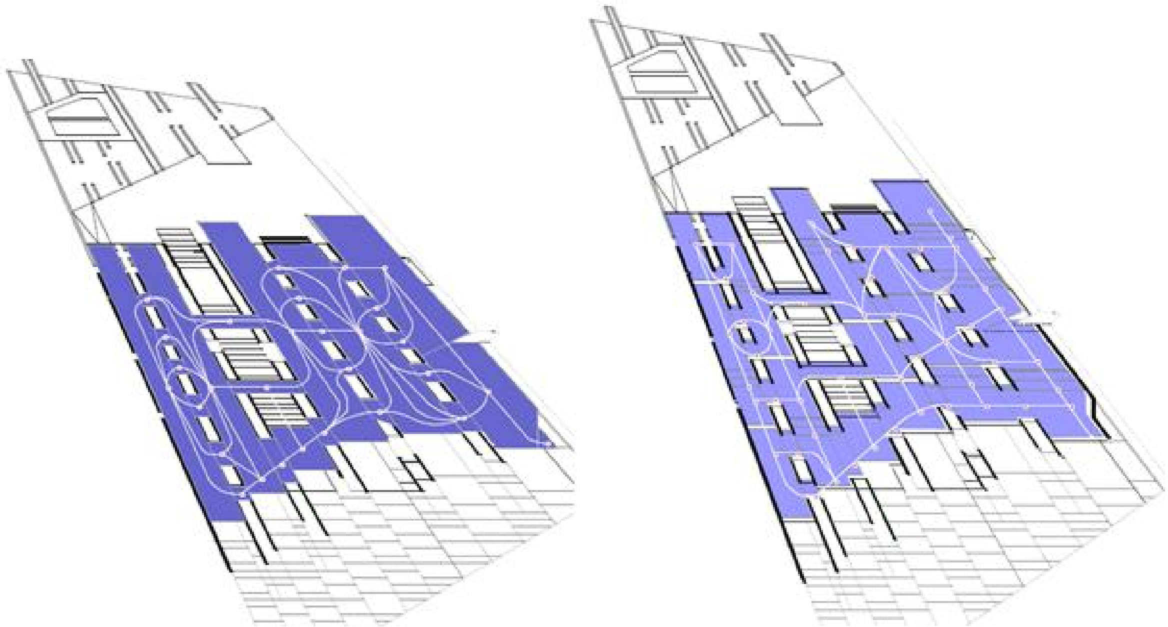


Figure 4.13 Convex spaces and visitor's circulation with and without ramps.
Source: METAPHOR JV, "*GEM, Circulation, and Way finding Schematic Design*".

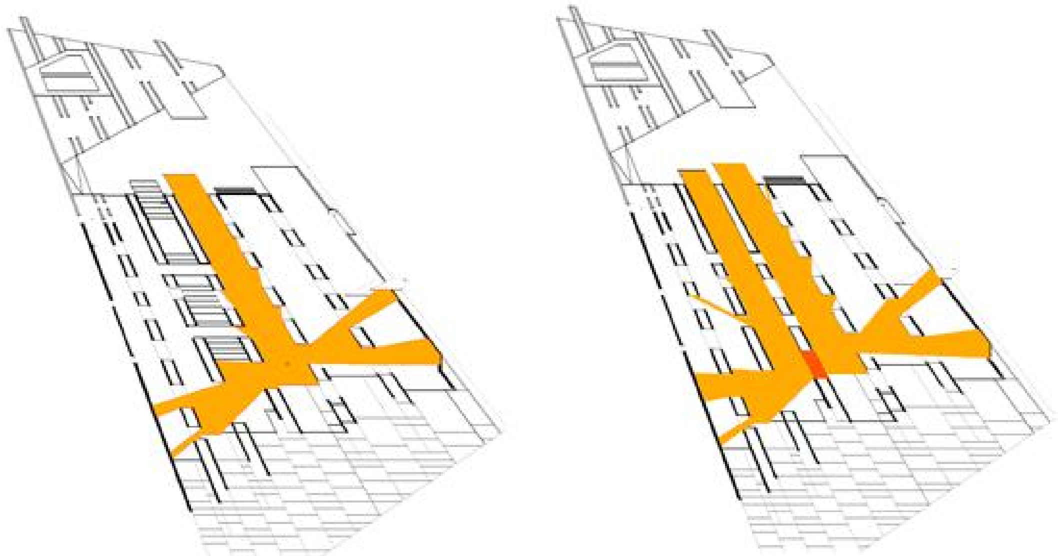


Figure 4.14 Isovisit study.
Source: METAPHOR JV, "*GEM, Circulation, and Way finding Schematic Design*".

In planning a themuseum route on such scale, it is important that visitors have a sense at all times of where they are going. In the GME, the Grand Staircase marks both the beginning and the end of the Visitor Experience. This confluence is important; visitors entering see the faces and responses of those leaving. They also know the way out. As they move around the Museum, visitors will need to be provided with views of key objects or displays that draw them through (axial views), and occasionally even wider sweeps of the collection as a whole (panoptic views). It is important in a building of this size that views are on a sufficient scale. Equally important to the visitor experience are elements of drama that are planned to come as a surprise and intentionally concealed from external view, as shown in figures (4.15) &(4.16).

Figure 4.15 The Dynamic view
Source: Heneghan.Pengarchitects, ARUP, BuroHappold JV"*GEM Pre-Schematic Design Report*".

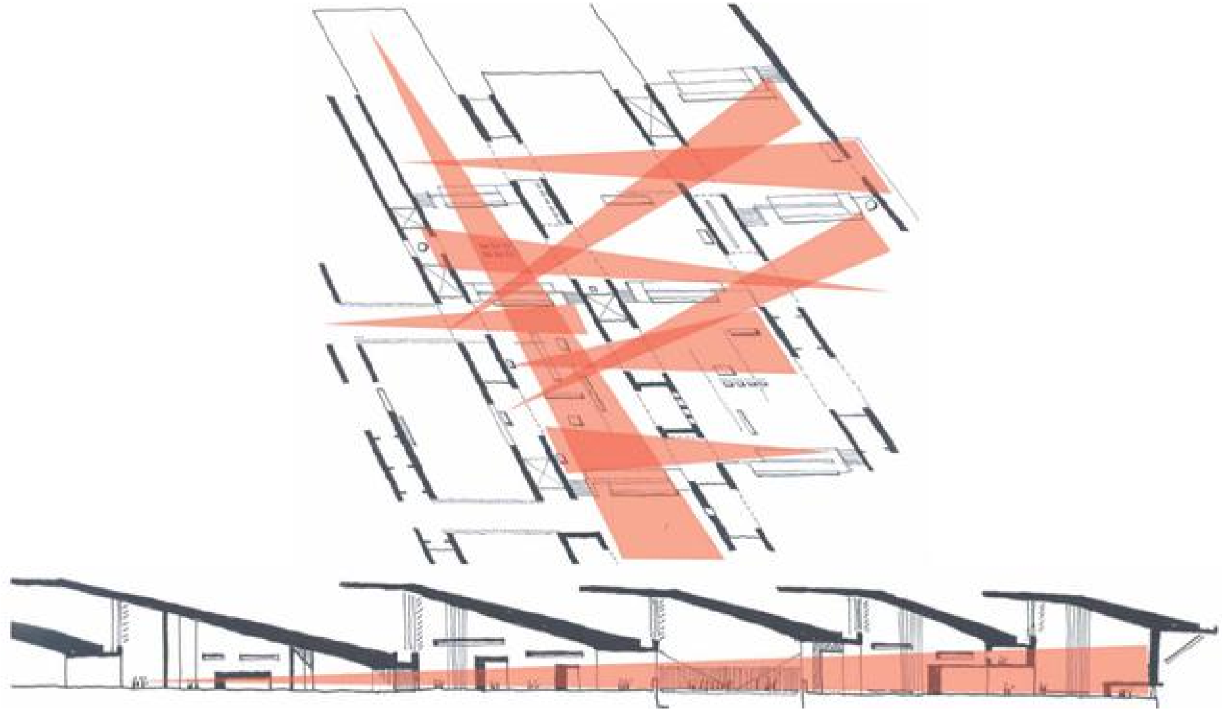


Figure 4.16 Cones of vision in plan and section.
Source: Heneghan.Pengarchitects, ARUP, BuroHappold JV"*GEM Pre-Schematic Design Report*".

Hyper textual Nodes are the key places where connections are made between the main Five Themes; however, these connections can also be made in individual displays. The Display Strategies will enable these connections to be made at every scale, from the *Macro*, displays at the scale of the whole Museum, to the *Micro*, displays within an individual showcase. Specific collections or single artifacts that connect several of the Themes are presented. For example, the Akhenaten collection brings together kingship and State, Religion and Society; Deir El Medina, Man and Society, Religion and Kingship and State. Individual artifacts, such as a gold threaded necklace from Tanis can tell us about The Land of Egypt, Man and Society and Kingship and State, as shown in figure (4.17).

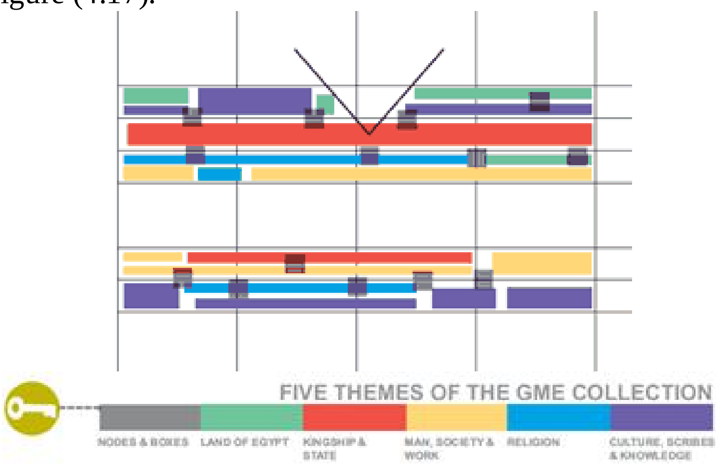


Figure 4.17 The main Five Themes displayed.
Source: Heneghan.Pengarchitects, ARUP, BuroHappold JV"*GEM Pre-Schematic Design Report*".

A key concept in the design for the GME is the laying of a chronological timeline along the north-south axis of the building, 15 meters per century. While this figure may be too rigid, the concept is strong and will be applied, as shown in figure (4.18). This move embeds the idea of chronology, and specifically the longevity of Dynastic time in the physical fabric of theMuseum. The Timeline provides the opportunity to use the building to make the visceral understanding of 3500 years of continuous civilization central to the Visitor Experience. Different design and display techniques can be used to reinforce the Timeline across the building as an integral part of the design of the floors, walls, graphic design, lighting, and signage.

Figure 4.18 The Chronology time line.
Source: Heneghan.Pengarchitects, ARUP, BuroHappold JV"*GEM Pre-Schematic Design Report*".

In the Exhibition display modes,the design of Museum galleries is divided into three main key levels: artifact display, information, and interpretation. These do not exist in isolation. They are layers within a larger visual context, made up from the panoptic and the axial view of the exhibits, pacing, and scale along the route, the setting of the building and the view of the Pyramids. Together, these layers are the Display Strategy that underpins the Visitor Experience.

Display strategies cannot be explored in isolation. They are part of a sequence of visual events and activities that makes up the Visitor Experience. Non-display strategies are of equal importance. For the visitor, rest areas, lounges, courtyards, and shopping occur within a single stream of activity that includes magnificent displays. The objective in museum planning is to make the changes between one activity and another as seamless as possible- from the arrival Welcome experience, to the Epilogue. Central to the development of the Masterplan for the GME is the integration of all the elements of the Visitor Experience; museology; organization and circulation; display and non-display strategies. This is achieved by investigating all the critical success factors in parallel, not sequentially in separate parcels. In this way, the Visitor Experience can be refined not only in terms of organization, and in terms of design, but as an economic entity. For example: it may be found after an evaluation of the international multi-lingual profile of Visitors, the length of their visits and their dwell times, that's not labelling individual objects in the conventional way may improve the Visitor Experience and also be more cost effective. The GME Exhibition Masterplan will address the full range of elements that constitute the Visitor Experience. It will identify projects that are hard design elements on tight programs that must be integrated with the architectural design process and others that can be programmed over a longer time span, even beyond the Museum opening, as shown in figure (4.19).

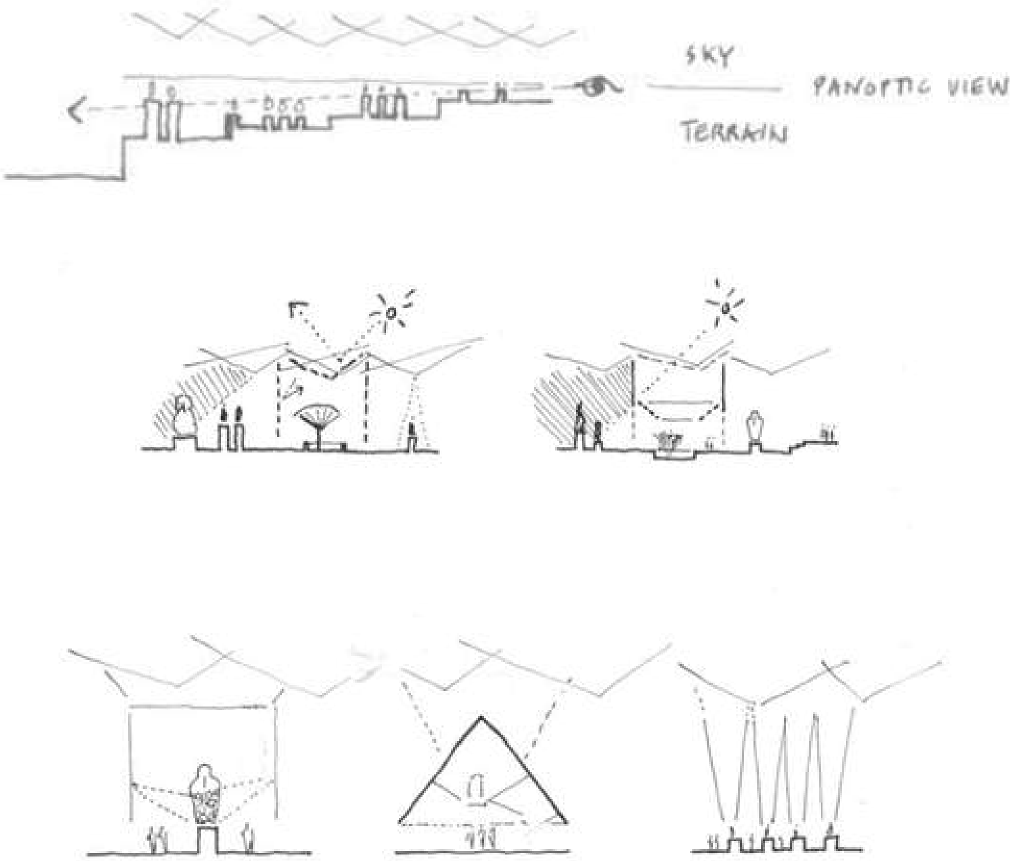


Figure 4.19 The building as exhibition maker.
Source: Heneghan.Pengarchitects, ARUP, BuroHappold JV"*GEM Pre-Schematic Design Report*".

4.3.2. The British Museum, London, UK[1].

Designer:	**Ian Ritchie, Foster & Partners Architects.**
Generation:	Plan Permutaion & Simulation – Space syntax. Roof design – Optimized by special algorithm.

One of the key objectives of the British Museum strategy is to extend the engagement between visitors and its collection. Space Syntax was commissioned by the British Museum to develop a baseline study of visitor movement patterns and of the spatial layout of the museum, as shown in figure (4.20). The general aims of the study were to explain how visitors were using the museum and to investigate the characteristics of its spatial layout and in order to establish the effect of the spatial layout on visitors' experience and develop a master plan for the gallery spaces. The baseline study was to improve visitor flow patterns. The design methodology was consisted of:-

- Observations of pedestrian flows, user routes and stationary activities
- Way finding studies
- Visibility analysis of public spaces
- Spatial accessibility analysis
- Option testing and evaluation
- Pedestrian movement simulation using computer agents
- Entrances' level of service and gallery occupation capacity analysis
- Visitors increase forecast and likely distribution within the building
- Evidence-based design advice.

Using visitor's data provided by the British Museum, together with data from direct observation studies, were able to assess the occupation capacity of entrances and gallery spaces and to estimate the capacity for future growth. Analysis allowed the designer to propose both strategic and highly design solutions as well as management changes, each aimed at addressing the strategic objective of extending and enhancing visitor engagement with the collection, as shown in figures (4.21), (4.22), (4.23), & (4.24).

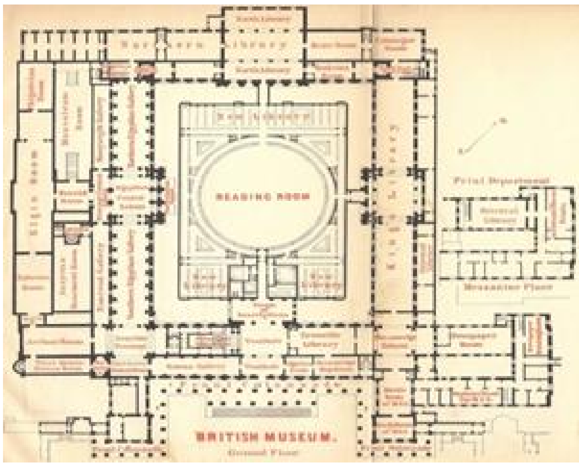


Figure 4.20 The British Museum plan.
Source: moodemapcollector.blogspot.com/2011/08/plan-of-british-museum-1894.html

(1)www.spacesyntax.com/project/british-museum/

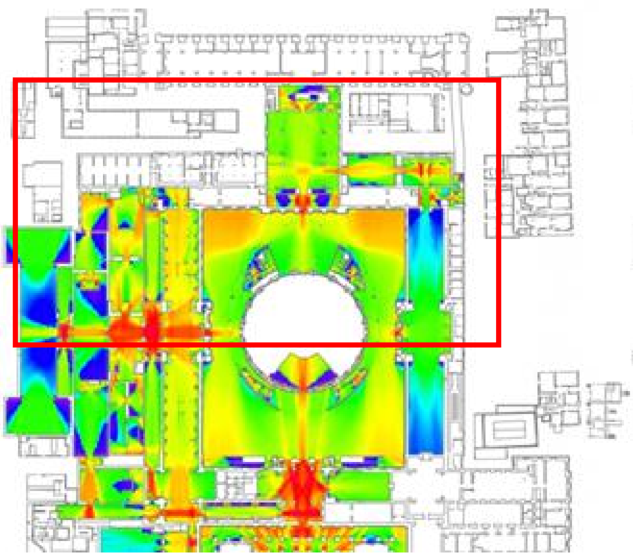


Figure 4.21 Spatial accessibility analysis (Showing key decision-making points in).
Source: www.spacesyntax.com/project/british-museum/.

Figure 4.22 Visitors movement survey .
Source: www.spacesyntax.com/project/british-museum/.

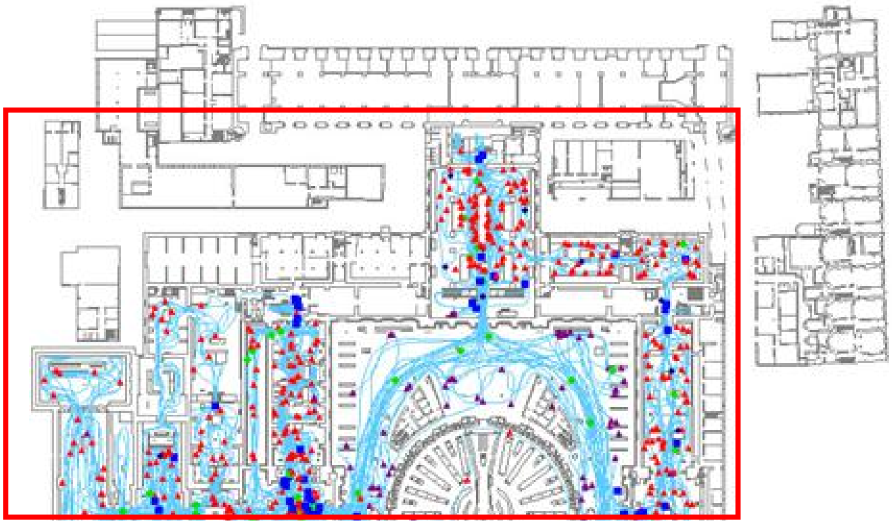


Figure 4.23 Visitor's movement traces
Source: www.spacesyntax.com/project/british-museum/.

Algorithms were used also in the design of the glazed roof spans of the British Museum circular reading room and the rectangular great court. The design changed the geometrical definition of the roof as it includes the roof shape and the steel members pattern. The designer used the NURBS surface techniques to define the roof surface geometry. The roof is rested horizontally on the corners and the resultant thrust is fixed by tension in the rectangular beam. The subdivision of steel members begins with a coarse mesh of surface and various types of generated grids, as shown in figures (4.24), (4.25) & (4.26).

Figure 4.24 British Museum (The Spiral walls).
Source: Burry. J & M, "*The new Mathematics of Architecture*", P (122).

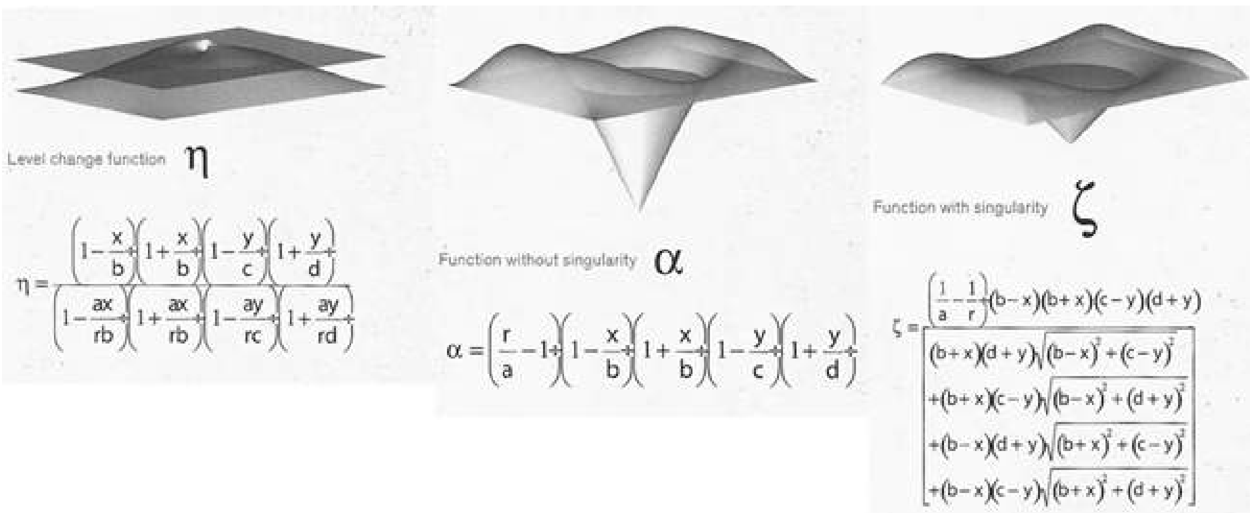


Figure 4.25 The Spiral walls ceiling equation.
Source: Burry. J & M, "The new Mathematics of Architecture", P (123).

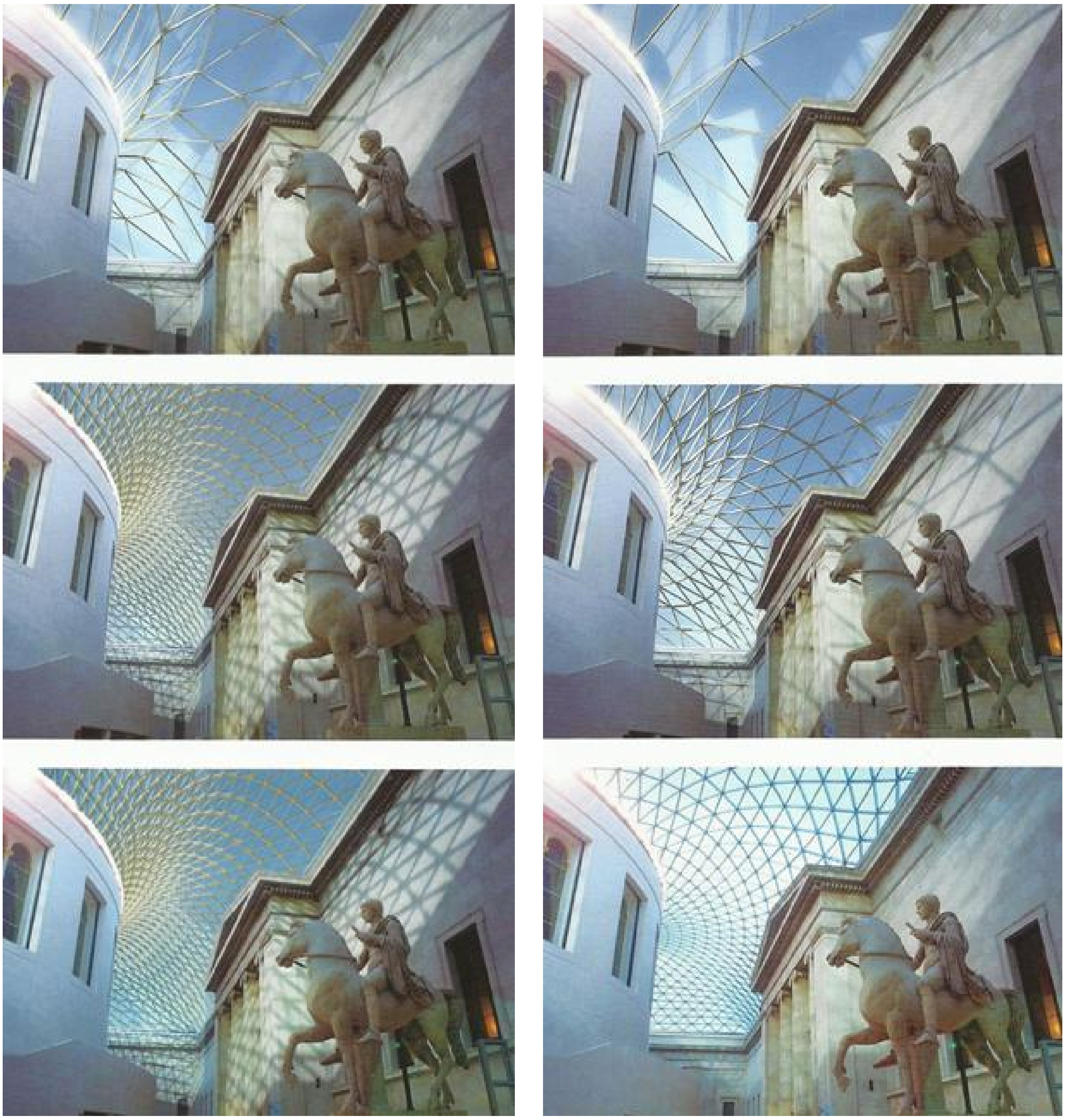


Figure 4.26 The Spiral walls ceiling optimization.
Source: Burry. J & M, “The new Mathematics of Architecture”, P (124-125).

4.3.3. Victoria & Albert Museum, The Spiral Extension, London, UK.

Designer:	**Daniel Libeskind.**
Generation:	Form generation – Fractal.

It is the winning proposal in the competition for the extension of Victoria & Albert Museum in London. The design concept is based on creating an anarchist spiral form presented by a mathematical formula such as fractal patterning. In the name of fractal a scaleless, non similar and periodic tiling created three tiles of fractal geometry, without repetation based on the multiple division. Each of the chosen tiles was subdivided into another three copies of it similar to the Golden Ratio by selecting the subdivided tiles, as shown in figures (4.27). The resulted tiles and lines crossing the tiles in different locations were transferred into the spiral walls, as shown in figures (4.28), (4.29) & (4.30).

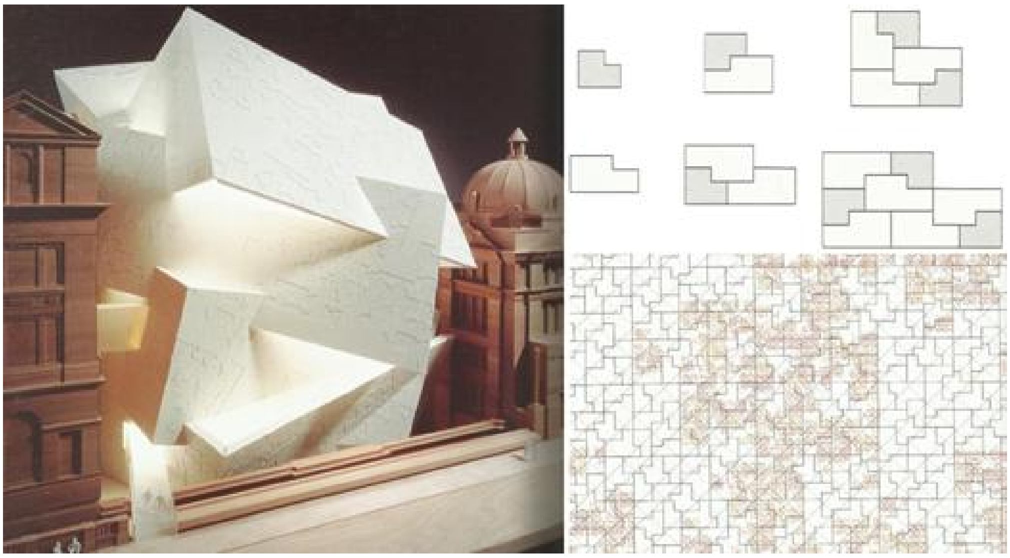


Figure 4.27 The Spiral Extension concept.
Source: - Burry. J & M, “The new Mathematics of Architecture”, P (98-100).

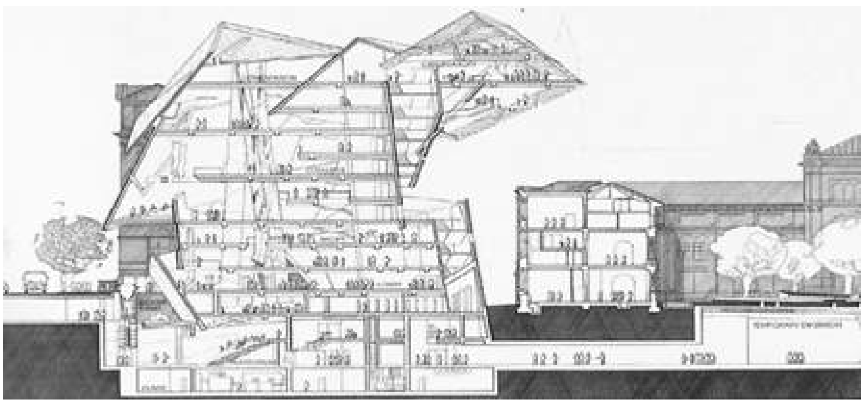


Figure 4.28 The Spiral section.
Source: - Burry. J & M, “The new Mathematics of Architecture”, P (101).

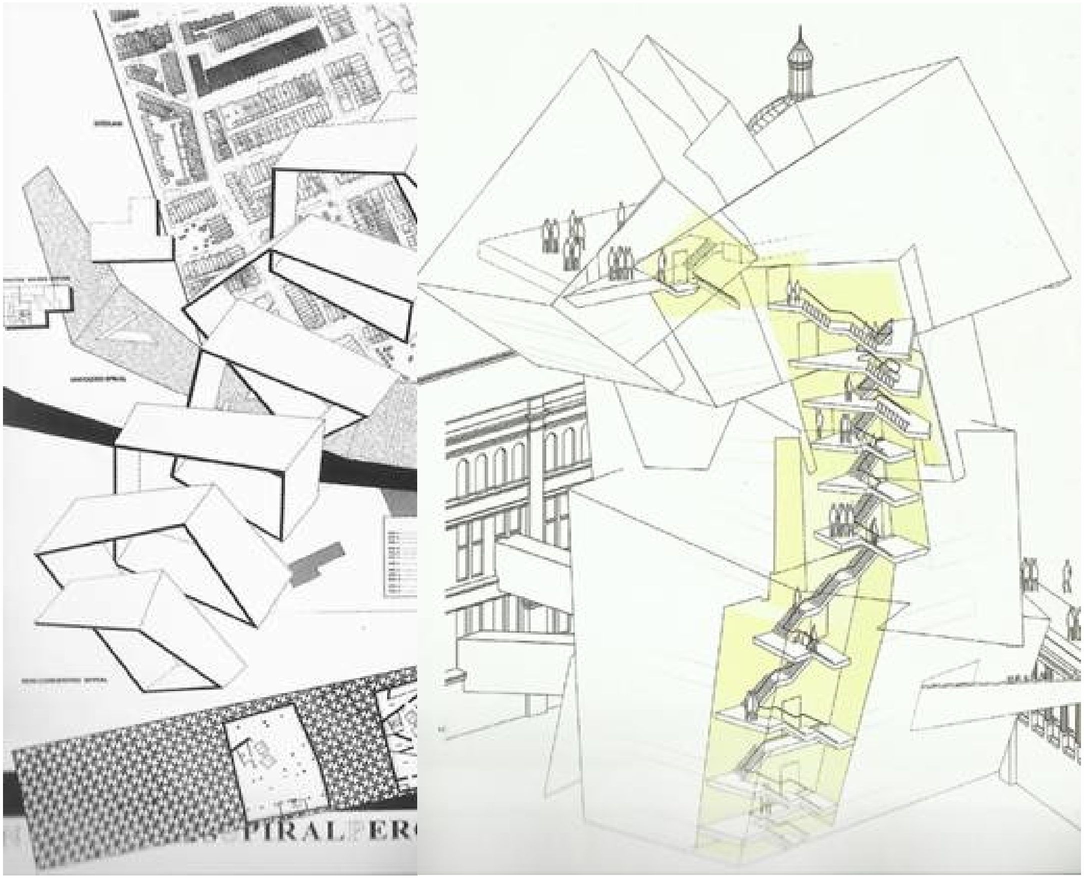


Figure 4.29 The Spiral 3D section and plan.
Source: Burry. J & M, “The new Mathematics of Architecture”, P (101).

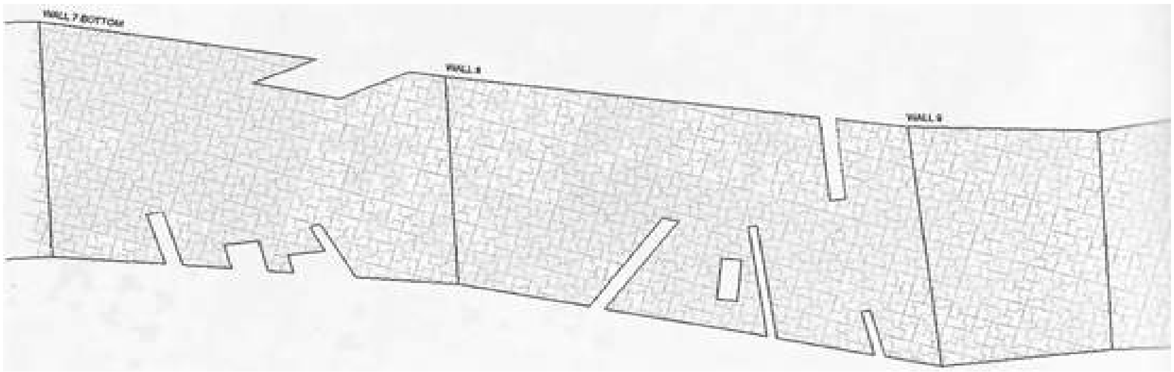


Figure 4.30 The Spiral walls.
Source: Burry. J & M, “The new Mathematics of Architecture”, P (100).

4.4. Conclusion.

As mentioned before in the previous chapters, Museum buildings design trends and forms are multiple, complicated and its design process is rapidly evolving. That is why it represents a challenge for any architect to think of designing such building.The main objective of this chapter was to drive the mutual relationship between utilizing algorithms on the architectural design and the architectural design of museum building, which was highlighted through five automated design stages (generation – permutation – optimization – simulation – transformation), by finding new mature forms, followed by generating appropriatefunctional plan, and studying it, until the complete design solution is reached. In order to give a clear explanation to the effect of this new trend in the architectural design of museums, three cases for different museum projects have been discussed.

In the next chapter, a detailed design methodology for the utilization of the Algorithmic applications in the design of Exhibition halls, in addition, an application for this methodology with two different scripts on an exhibition hall will be introduced.

Chapter 5: Museum Exhibition hall Arrangement using Algorithms.

5.1. Introduction.

As mentioned before in the previous chapters, the Architectural design could be more efficient and practical when it is generated,and examined by Algorithms. This new trend has been emerged in the architectural design evolution, based on simulating theecological relationsin the biological paradigms, and generations. Based on that, the computer-aided programs get useful of these paradigms, and became the main evolver of the upcoming design for new software. That helped the architectural design to overtake many of the design stages, and obtain more advanced design solutions. As a result, the design of museum exhibition halls has been affected by this new design technology.

Museum buildings are classified as public buildings; so the rules of designing public buildings should be followed, which care mainly about the interaction between the space user and the space design. When the Exhibition Halls became the main reason to establish museums and its core, it became a need to study the most public space inside the museum taking into consideration the main factors that affect its design, which were described before. In this chapter, the design of exhibition hall by algorithms will be highlighted through an application based on an algorithmic design methodology.

5.2. Exhibition Hall Design.

Designing a museum exhibition is aboutarranging exhibits in both attractive and educational way. In many instances, the careful planning of museum exhibition is the responsibility ofthe museum exhibit designer. Planning a museum exhibition is about visualizing the exhibits arrangement in each hall of the museum, in which, the museum cultural message will be presented. The exhibits in a museum are typically set up; so that they are placed, and displayed as naturally as possible, in accordance with the museum size, and budget. Some exhibits are designed to be permanently exhibited in the museum, while others are temporarily exhibited, according to the exhibits type and the exhibition technique, the exhibits type and size, as shown in figure (5.1). Some of these exhibits are designed to allow the visitors to interact with them, while others must be protected from curious visitors. In addition, the different lighting systems to make the exhibits easily to be visible should be considered in the initial stage.

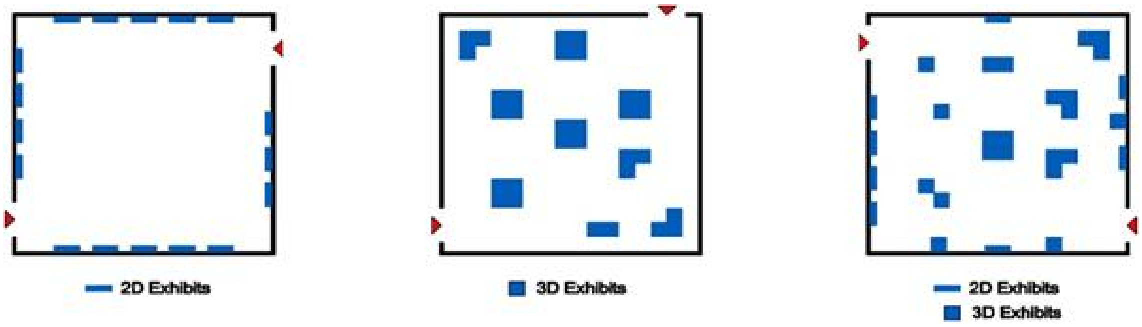


Figure 5.1 Hall arrangement according to Exhibits type and size.
Source: Done by Researcher.

In the next stage, the designer is up to create a visual representation of the exhibition design by sketching the future exhibits or using sophisticated design software, as shown in figure (5.2).

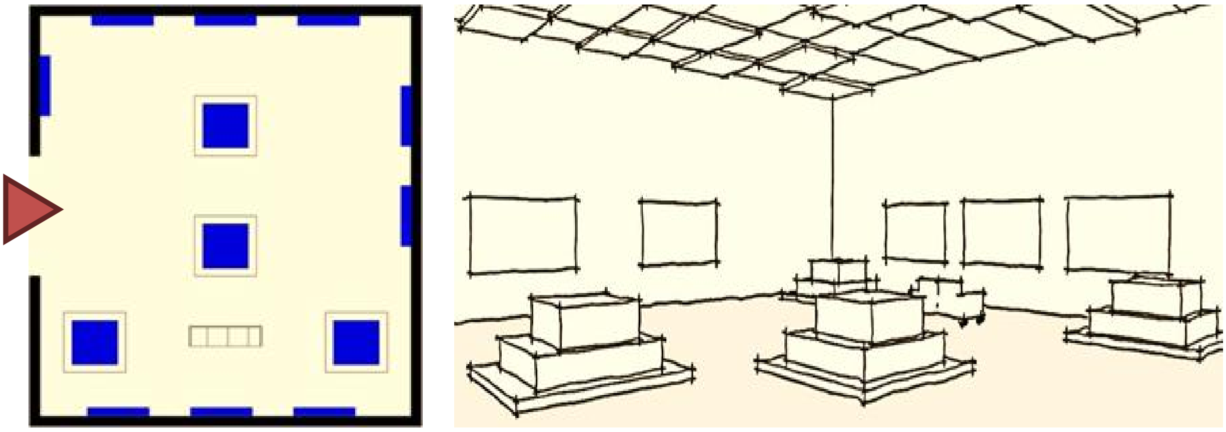


Figure 5.2 Visual presentation of future exhibits in 2D & 3D.
Source: Done by Researcher.

In this stage, the designer has to study all the consequences resulted from this design on the visitor's movement, as shown in figures (5.3) and (5.4), which will be followed with some modifications, before setting the exhibits up in their final location, as shown in figures (5.4).

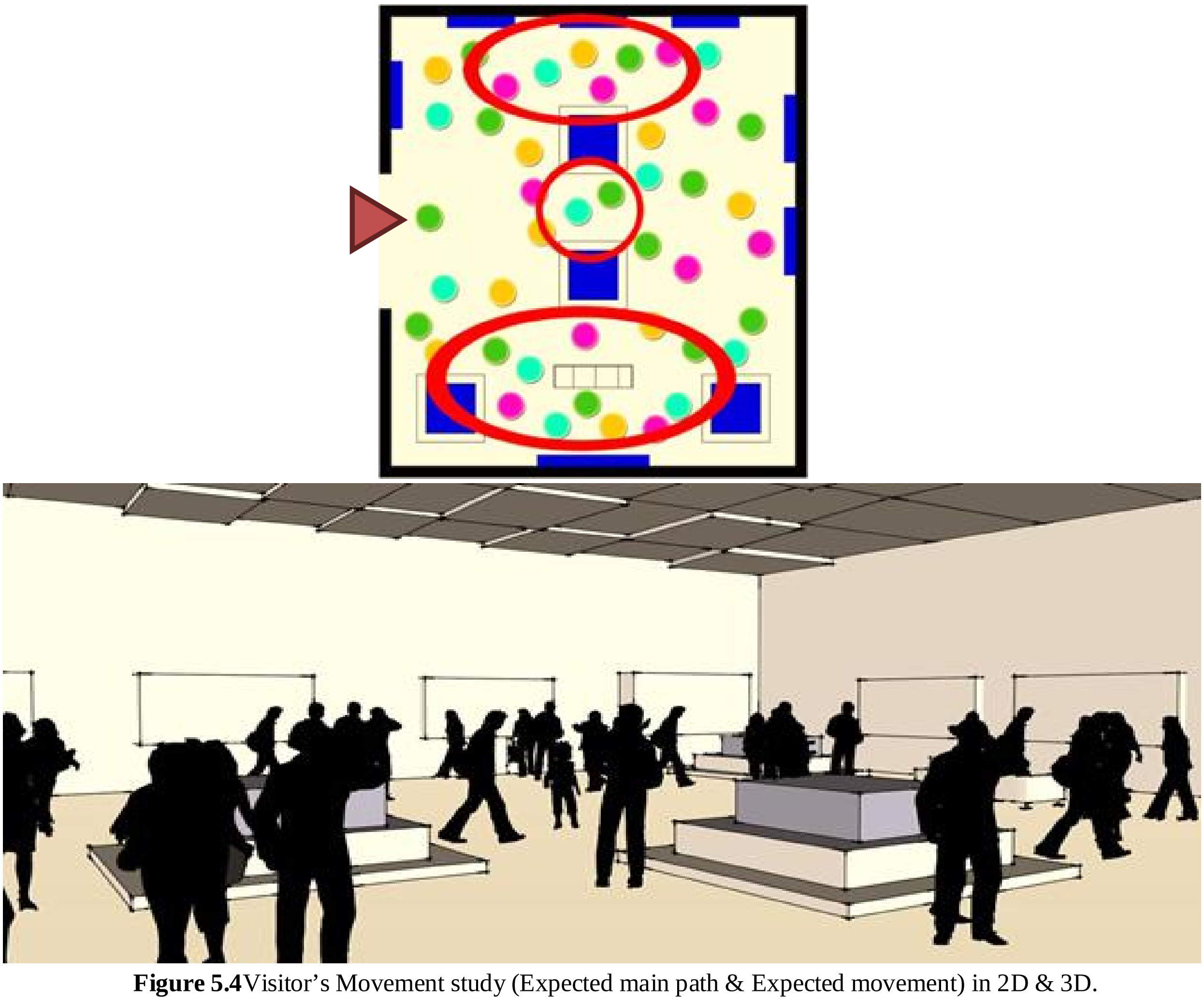


Figure 5.4 Visitor's Movement study (Expected main path & Expected movement) in 2D & 3D.
Source: Done by Researcher.

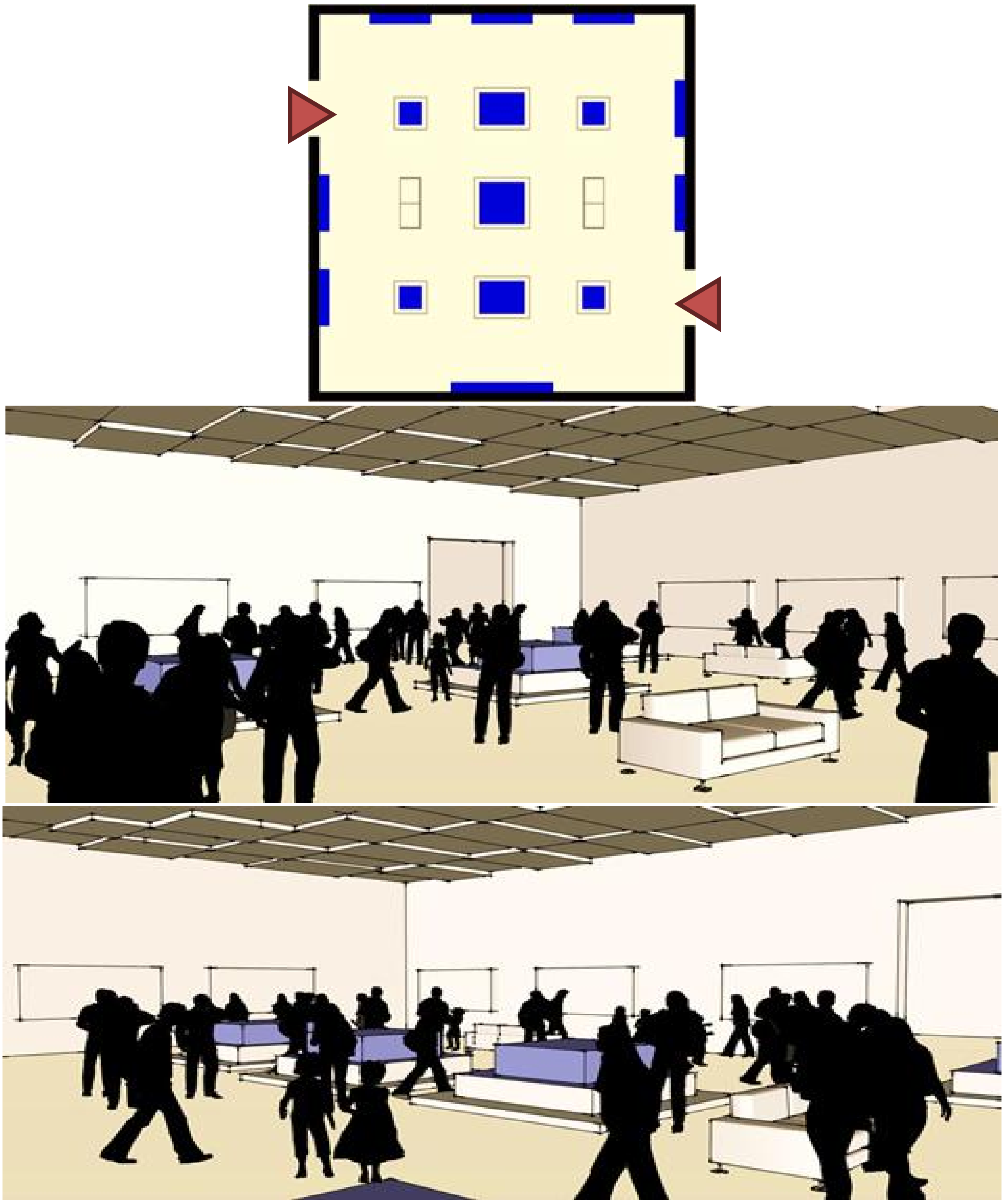


Figure 5.4 Exhibition hall design.
Source: Done by Researcher.

This design methodology could be described, and implemented digitally using algorithms. During the design stage, algorithms could be operated in order to set up the exhibits in their initial location, thus getting more solutions for this arrangement, in addition to study the visitor's movement and its impact on the exhibition design, until the final arrangement is reached.

5.3. Automated Design process.

In order to get a full exhibition hall design, certain methodology will be followed, to achieve the previously discussed objectives. With the help of some algorithms such as (Cellular Automata, Swarm Intelligence…etc.), number of solutions will be generated and evaluated for the hall arrangement. Firstly, some decisions should be taken by the architect, in addition, the previously stated regulation of the exhibition hall design and visitor's movement should be considered in the Generation and simulation stages, as followed:

5.3.1. Design Methodology.

To express the effect of this new methodology using Algorithms in the exhibition hall design, the design process is presented in a matrix, including description of the four stages of design, as in table (5.1), and explained as follows:-

- **First stage: - Decision Making**

  In this stage, some decisions should be taken before starting the design. As discussed above, the museum type and size should be decided first, which leads to select the type of the exhibited artifacts and their size. In addition, the display strategy will be decided according to the museum cultural message that will affect the exhibition hall design including shape, entrances, and its arrangement, which will be the next stage inputs.

- **Second stage: - Exhibition arrangement (Generating stage& Permutation stage).**

  In this stage, exhibits are about to be arranged according to some certain rules as a result of the previously selected display strategy, the exhibits will be located in their initial location. Then, the exhibits will be moved to new locations by time, in order to get the largest number of alternatives to be evaluated through the next stage.

  - **Script A**: - The main script will run containing some sub-scripts, in order to generate the largest number of alternatives, as in figure(5.5).
    - **Step A.1**: **Creating cellular massing grid with certain dimensions**.
      This grid is going to be the basic pattern to place exhibits and for the visitors' movement in the hall. This pattern helps to study the visitors' perception along the movement path. It shall be designed in accordance with the size of exhibits and the personal space (visitors' territory) dimensions.
    - **Step A.2**: **Placing exhibits in their initial places**.
      In order to obtain variety of alternatives, exhibits shall be located in a certain arrangement. This arrangement will be in accordance with the exhibition technique and approach (e.g., small exhibits are collected in a specified area and other exhibits are located in different areas in the hall). The exhibits original location is considered as their initial state.

- **Step A.3: Using time controller to produce alternatives by time.**
  Using time controller as a generator, in order to produce new alternatives in time, exhibits will be relocated in a different location than their initial state according to a certain technique.
- **Step A.4**: **Generating alternatives for exhibits arrangement on the cellular grid**.
  Number of different alternatives is generated in a certain time to be studied in detail to choose the most suitable alternative using script B.

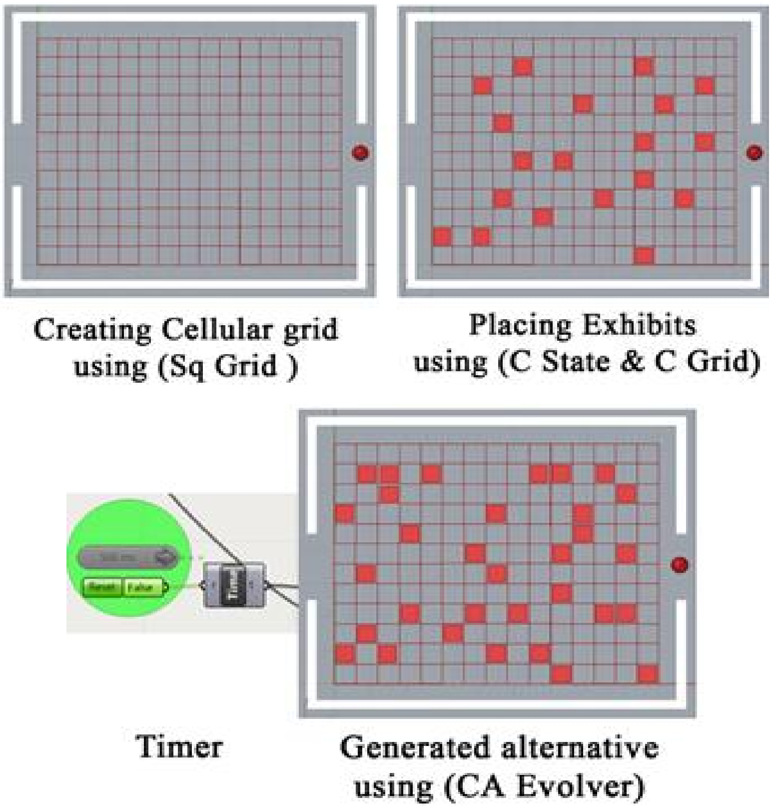


Figure 5.5 Script A.
Source: Done by Researcher.

- **Script B**: - It is an evaluation script, which will be run to choose the most suitable alternatives, based on certain parameters and arrangement criteria to be selected by the architect (e.g. decide the minimum space between each group of exhibits, check the place of small size exhibits compared to the bigger one if it matches with the display strategy, check if the visitor's path through the hall is recognizable). In case none of the evaluated alternatives passed this step, the script will go back to step A.2.

The results of this stage areone or more alternatives will be selected from the generated list, which satisfies the exhibition arrangement rules.

- **Third stage: - Exhibition arrangement & Visitors' Behavior (Simulation stage).**

  In order to examine the interaction between the visitors and the built environment, a simulation is made to study the visitors' movement and their visual field along the movement path. Before this simulation, an evaluation step is made to check the ability of visitors to move freely and safely inside the hall, which will make some modifications to the chosen alternatives.

  - **Script C**: - Using Isovisit script, to check the visitors' field of vision, which presents the visitors' ability to recognize most of exhibited artifacts in certain areas and location of exits from any point along the path, as in figure (5.6).
    - **Step C.1**: Determine the visitors' path.
      The visitors' path is very important, as it is the path that visitors follow to see most of exhibited pieces inside the hall according to the purpose of the museum.
      Step C.2: Identifying hall boundaries and exhibited artifact location.
      In order to study the visitors' visual field, each exhibit is considered as a block inside the hall and the hall boundaries that could obstruct the visitors' visual line for a certain distance.
    - **Step C.3**: Tracing visitor movement and visual field.
      In this step, the script runs according to the previously identified data, to draw the visitors' visual rays along the path, taking into consideration the visitors' eye level, the exhibits height and the path that will increase the visitors' ability to see more exhibits.

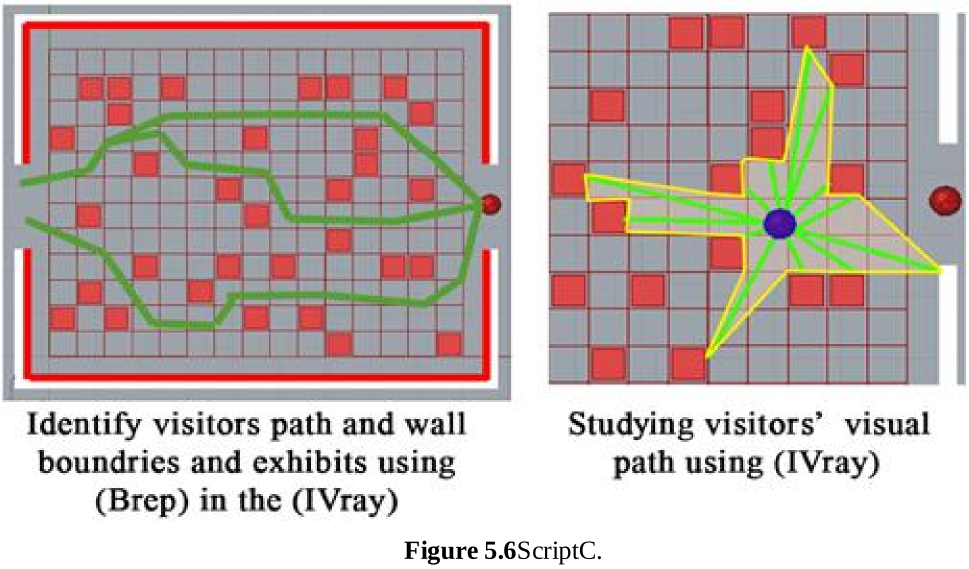


Figure 5.6 ScriptC.
Source: Done by Researcher.

The results of this step will change the hall arrangement resulting from the second stage after the visual field study to improve the visitors' ability to see most of exhibited artifacts.

- **Script D**: - In order to trace the movement of visitors, this script studies the visitors' behavior in the hall, as in figure (5.7).
  - **Step D.1**: Identifying hall boundaries and exhibited artifact location.
    In this step, each exhibit is identified as a block inside the hall and the hall boundaries.
  - **Step D.2**: Tracing four groups of visitors (presenting the four movement styles).
    In order to trace visitors' behavior in the exhibition hall, a simulation will be made depending on the visitors' different movement styles inside museums (Ant – Fish – Grasshopper – Butterfly), taking into consideration the personal space (territory) radius, in addition to the minimum required space between visitors and artifacts.

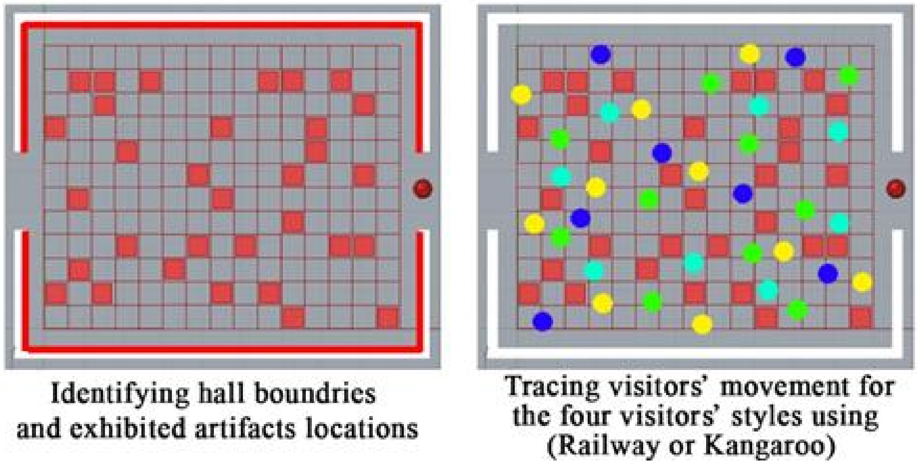


Figure 5.7 Script D.
Source: Done by Researcher.

- **Fourth stage: -The final exhibition area has been presented after the recent modifications.**
  Some modifications may take place on the hall arrangement because of some errors that appeared during visitors' behavior simulation. In order to facilitate the visitors' movement during their visit, the final design shall be tested until no errors appear, as in figure (5.8).

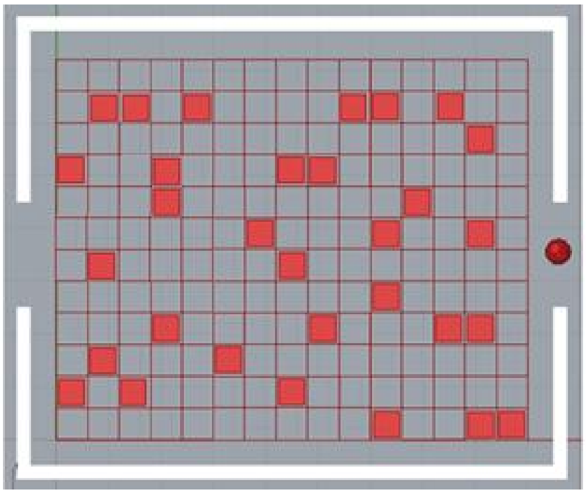


Figure 5.8 Stage No.4 Final exhibition area.
Source: Done by Researcher.

Table 5.1 Design process.

Source: - Done by the researcher.

First stage: - Decision Making. To be decided by the Designer, as Inputs	A. Regarding Museum	• Museum Type.	According to branch of Knowledge						
			History Museum	Natural history and Science Museums	Art Museum	General or specialized Museums			
		• Museum Size.	Small	Medium	Big				
		• Exhibits Type. 2D	Textiles	Documents	Paintings	Posters	Printings		
		3D	Sculptures	Mummies	Animals	Instruments	Inventions		
		• Exhibition Technique	Historical Presentation (Presentation method depends on heritage revitalization by arranging pieces in historical sequence, or in the form of telling a story using the exhibited pieces).	Ecological presentation (Presentation method depends on creating the real environment for the presented organisms or making an interaction between visitors and the Inventions).	Aesthetic presentation (Every piece from the collection presented separately or collected in an aethetic way).				
	B. Regarding the Exhibition Hall	• Hall Shape.	Regular shape			Irregular shape (According to hall's cluster			
			Rectangular	Squealer	Circular				
		• Hall Type.	Main Hall	Temporary Hall					
		• Hall Dimensions.	(7m*21m*4m)	(8m*27m*6m)	(5m*12m*4 m)	(6m*17m*6m)			
		• Entrances and Exits locations.	Both entrance and exit on the same wall.	Entrance and exit on two opposite walls.	Entrance and exit walls are perpendicular	Entrance and exit are the same opening.			
Second stage: - Exhibits arrangement. Partially or full automated	Arrangement	• Random Arrangement (In case the exhibited pieces are of the same type and size).	**Step 1: -** i. An algorithm will work in order to make a random arrangement for the selected exhibits with its size, neglecting its priorities. ii. An infinite No. of alternatives was generated.			**Description:-** - (i & ii) Fully Automated design using **Cellular Automata Algorithm.**	**Step 2: -** - An evaluation step for the generated alternatives. - According to the hall's arrangement rules, the most suitable alternative was chosen.	**Description:-** To be implemented by the **Designer** or using **Stochastic Search Algorithm** in addition to **Genatic Algorithm** with fitness function, or to be done by the architect.	An Alternative is selected from Random arrangement.
		• Selective Arrangement (In case the exhibited pieces are different in type and size).	**Step 1: -** i. Selecting the most suitable exhibits to be presented on the previously selected hall (type – size). ii. Arranging exhibits according to their priorities (the most important exhibits or the biggest at first, then the rest of exhibits). iii. An algorithm will work in order to arrange the rest exhibits in the resulted and selected empty spaces.			**Description:-** - (i & ii) To be decided by the designer or using **Voronoi Algorithm** to divided the hall into small areas. - (iii) To be done through automated design using **Cellular Automata & Genetic Algorithm (optional).**			An Alternative is selected from Selective arrangement.
Third stage: - Visitors Behavior. Studied by the designer and achieved by automation	A. Perception	• Exhibits Perception.	**Step1:-** i. Predicting the visitor's path through the hall. ii. Studying visual field from any point along the movement path.			**Description:-** - (i&ii) Deciding and simulating the visitor's visual field from any point along the path. Using **Isovist of Space Syntax theory** - Automated step.	**Step2: -** An evaluation step to check the ability of visitors to see most of exhibits and exits from any point inside the hall.	**Description:-** To be checked by the designer or an error will occur during the simulation.	The resulted arrangement after some modifications will be checked in the next steps.
	B. Movement	• Visitor's styles of physical Movement.	**Step1:-** i. Simulating the four visitor's movement style swarm for Ant, Fish, Butterfly, and Grasshopper visitors. ii. According to these movement styles; a study for random movement in case of emergency.			**Description:-** - (i) In order to see the effect of exhibits arrangement on the visitor's movement, a simulation using **Swarm Intelligence algorithm** will be tested. - (ii) For visitor's behavior in case of emergency and the longest distance from any point on the path an **A* Algorithm** will be used.	**Step2: -** An evaluation step to check the ability of visitors to move freely and safety inside the hall.	**Description:-** To be checked by the designer or an error will occur during the simulation.	**Final Alternative:-** The resulted final design of the hall after the last modifications.

Selected case.   Final Alternative

5.3.2. Application.

A. Required to prove.

The mutual relationship between the **Architectural Design of Museums,** and the **Emergence of New Evolution Design Methods**, represented in Algorithms application.Free hall has been designed to apply the previous explained phases and stages of design, according to a full functional program in table (5.2), with a zoning plan in figure (5.9) for a museum.

B. Given.

Table 5.2 Proposed museum functional program[1].

Space	No of spaces	Width*Length*Height	Total area
Zone A (Public spaces)			
Main Exhibition Hall	1	(7m*21m*4m) to (8m*27m*6m)	147m2 to 216m2
Temporary Exhibition hall	1 to (According to the designer & the museum size)	(5m*12m*4m) to (6m*17m*6m)	60m2 to 102m2
Outdoor Exhibition	1 to 2	(5m*7m)	
Library	1 main for public and researchers	(12m*21m*4m)	252m2
Special Event Halls	2 halls	(7m*8m*4m)*2	112m2
Computer lab & Show room	2	(4m*5m*4m)*2	40m2
Gift Shop	1 to 2	(3m*4m*3m)	12m2
Restaurant & Cafe	2	(7m*8m*3m) with kitchen(4.5m*5.5m*3m) & (5m*8m*3m)	56m2+24.75m2 & 40 m2
Circulation area	**Assumed**		50m2
Zone B (Administration spaces)			
Museum Manger room	1	(3.5m*4m*3.5m)	**14m2**
Staff & Workers rooms	4	(3m*3m*3m)*4	**36m2**
Security desk	1	(2m*3m)	**6m2**
Storage Supervisor	2	(3m*3.5m*3m)*2	**21m2**
Exhibition Supervisor	2	(3m*3.5m*3m)*2	**21m2**
Circulation area	**Assumed**		**17m2**
Zone C (Exhibition services)			
Big storage	1	(12m*15m*7m)	**180m2**
Reservation Laboratories	4	(5m*6m*5m)*4	**120m2**
Library	1	(10m*10m*4m)	**100m2**
Preparation area	1	(5m*7m*6m)	**35m2**
Exhibition support	1	(7m*10m*5m)	**70m2**
Circulation area	**Assumed**		**35m2**
Total area			**1404.25m2**

[1]From :
- Ibid, Dean. D,P (32 - 90).
- Ibid, Chiara. J, Callender. J, P (329 - 340).
- Ibid, Gay Hunt, E.

- **Proposed museum-zoning diagram.**

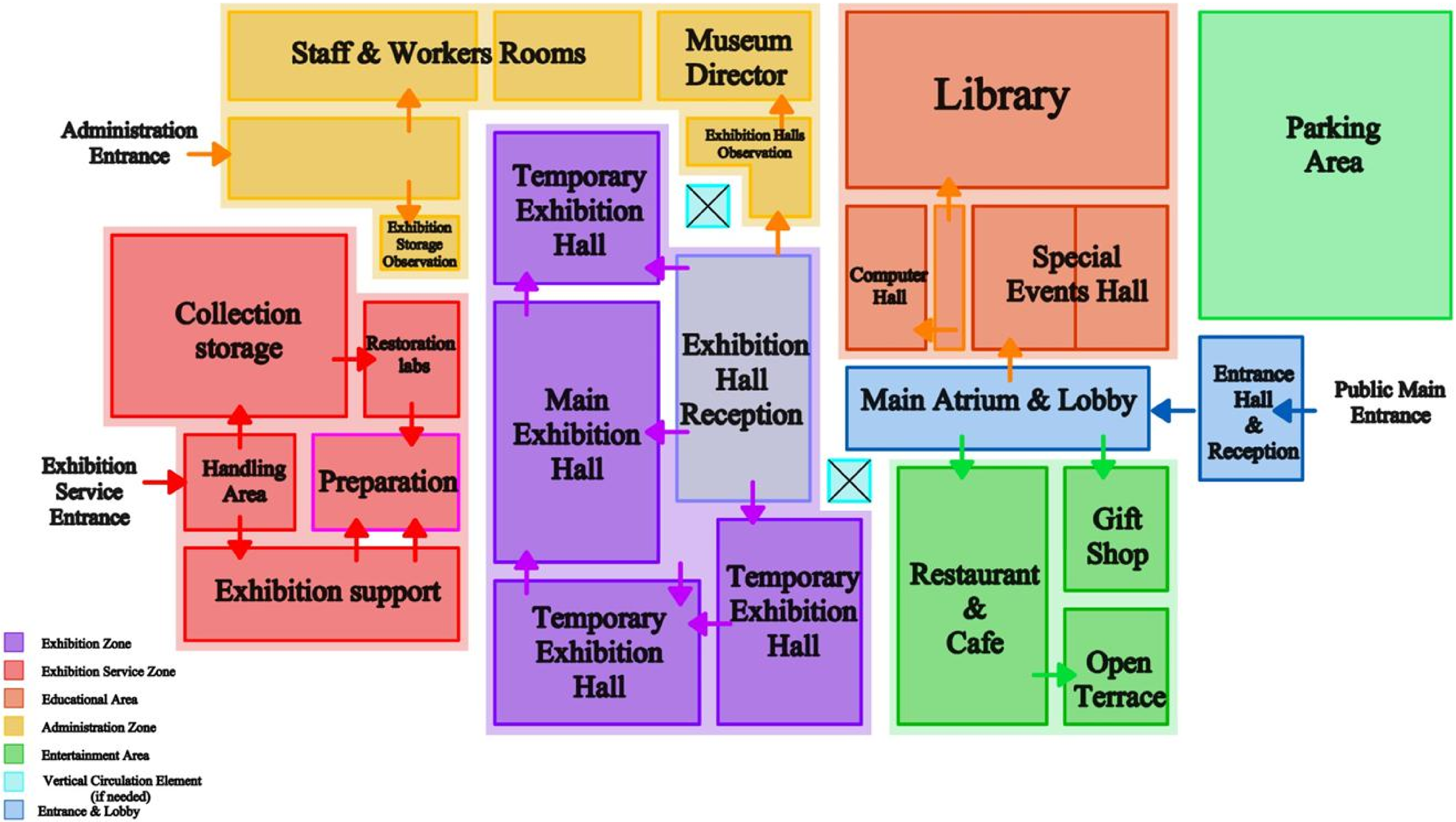
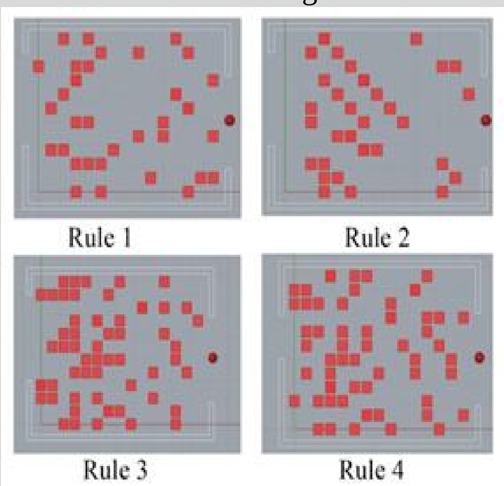
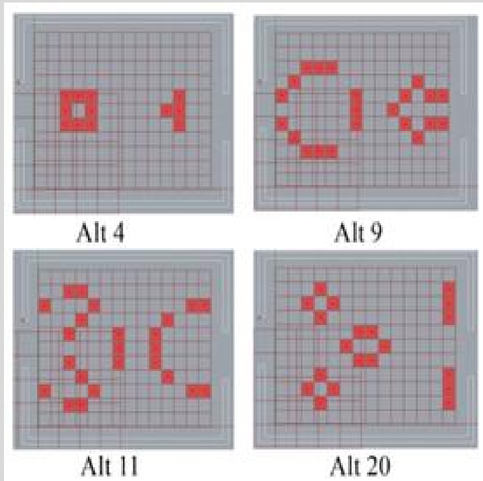


Figure 5.9 Proposed museum zoning.
Source: - Done by the researcher.

C. Proof.

According to the previously discussed Methodology, the arrangement of museum exhibition hall could be achieved in different techniques.The application has been made through a comparison between two different ways to arrange exhibits in the same hall, using Rhinoceros& Grasshopper platform, explained as shown in table (5.3).

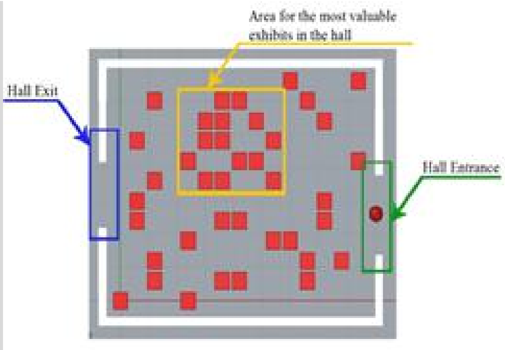
Table 5.3 General application.

<table>
<tr><th colspan="3">• First stage: Decision Making</th></tr>
<tr><td colspan="3">- Museum type: Art Museum.
- Exhibits: Sculptures.
- Hall dimensions (Width = 17m - Length = 6m - Height = 6.0m).
- Human scale (Tall ≅1.70m), Personal territory (Radius = 0.9m), Speed≅ 20 ft. /min.
- No. of exhibited pieces = 25 to 50 piece, each piece with area = 0.5 to 11.5m^2, height=0.5m.
- Expected No. of visitors = 15 to 50 people.
- The expected visitor’s movement styles in the hall (Ant – Grasshopper – Fish – Butterfly).
- Global force = 0.5 to 1.2 N, with speed = 0.5 to 1m/s.</td></tr>
<tr><th colspan="3">• Second stage: - Exhibition arrangement (Generating stage & Permutation stage).</th></tr>
<tr><td rowspan="3">Script A</td><td>Proposal 1</td><td>Proposal 2</td></tr>
<tr><td>Cellular Automata Algorithm (Cell repetition).
- Choosing an elementary prototype cell rule.
- Creating 1D cellular space in X direction.
- Creating Y direction rule for repetition.
- Initial cells state.
- Manual control to generate alternatives for living cells.

</td><td>Cellular Automata Algorithm (Conway’s Game of life).
- Defining evolution’s rules.
- Creating 2D cellular space to move.
- Choosing a popular configuration formation of cells.
- Timer control to generate alternatives for living cells.

</td></tr>
<tr><td>Result = ∞ No. of Alternatives.</td><td>Result = ∞ No. of Alternatives.</td></tr>
</table>

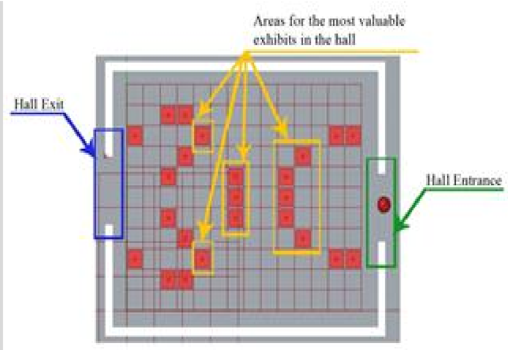
Script B

Stochastic search Algorithm.

- An evaluation step for the generated alternatives.
- The most suitable alternative was chosen, according to the hall arrangement rules.



Result = Alternative of Rule No.9.



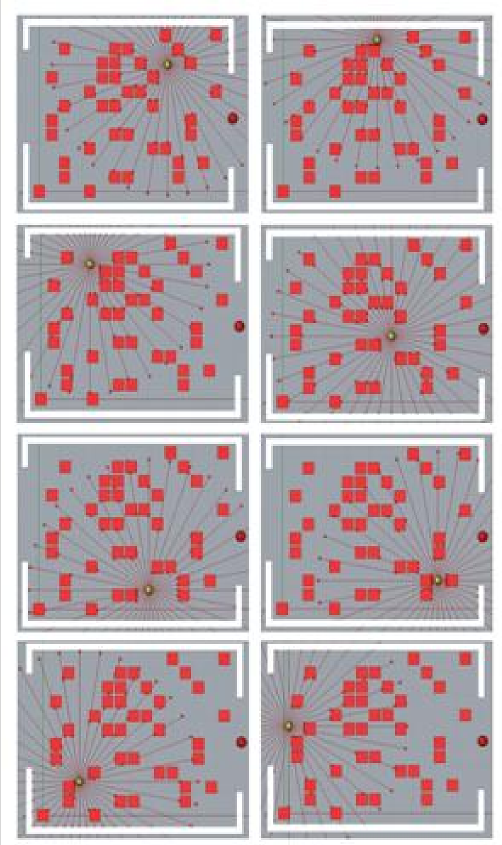
Result = Alternative No.11.

- **Third stage: - Exhibition arrangement & Visitors' Behavior (Simulation stage).**

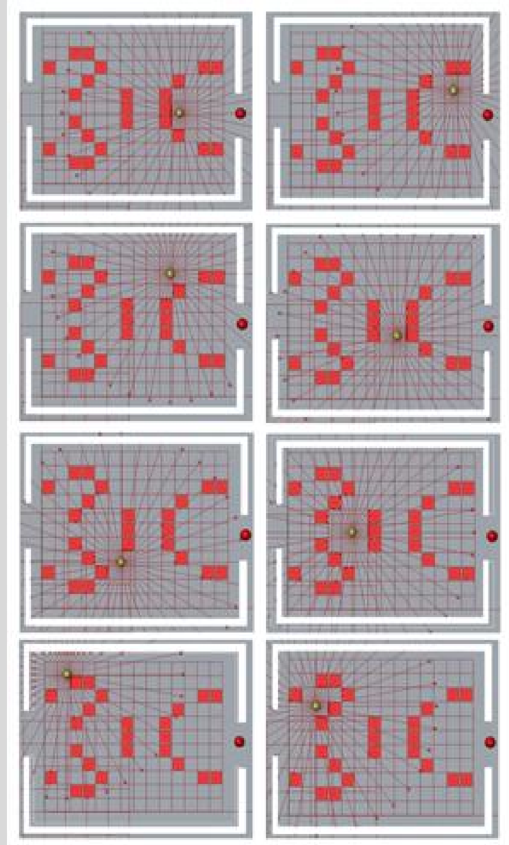
Script C

Isovisit

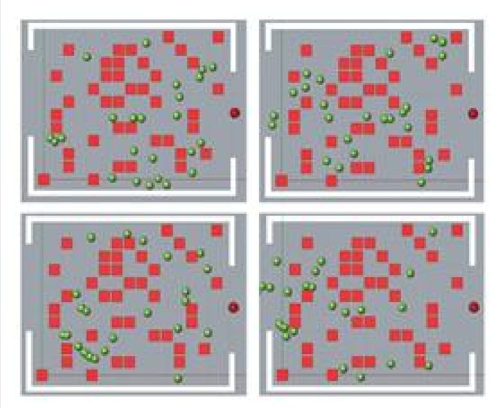
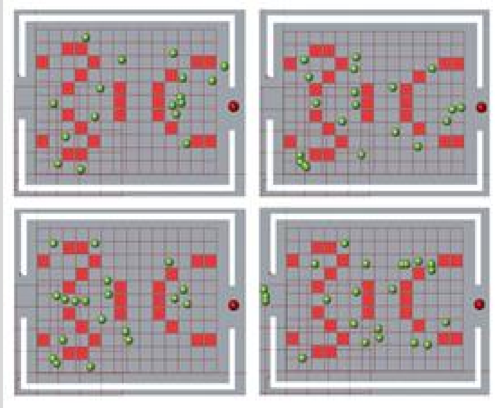
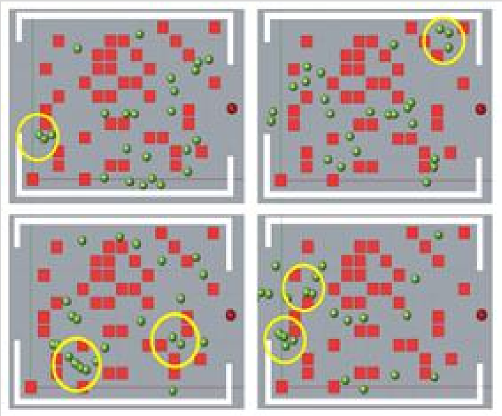
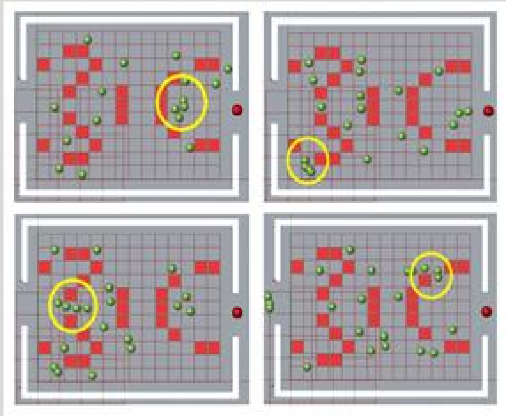
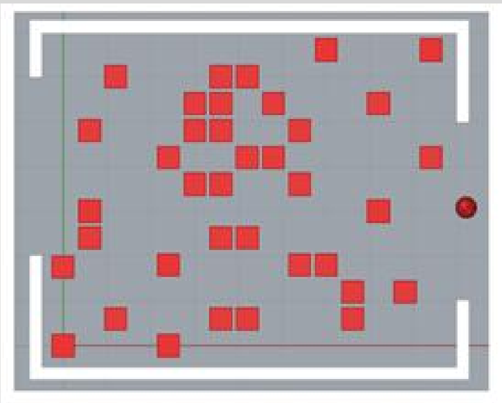
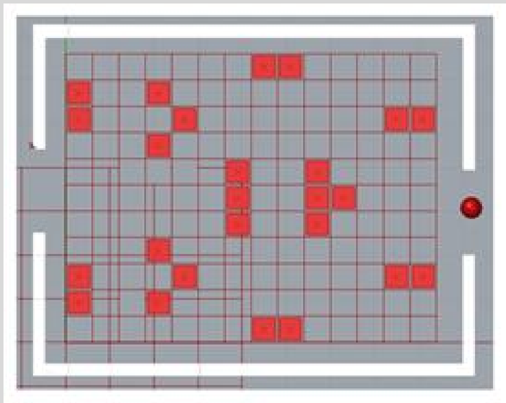
Isovist test, studying the visual field from any point along the movement path, exhibits height is the same and if not the visual field will be changed.



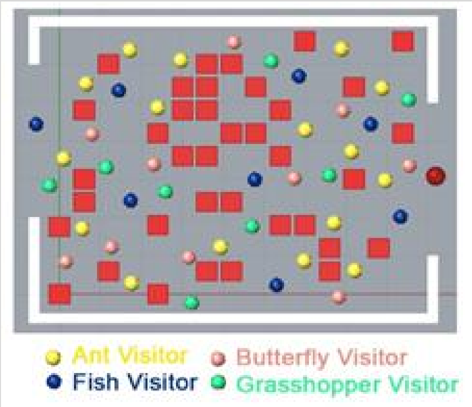
View 360° from different points along the path.

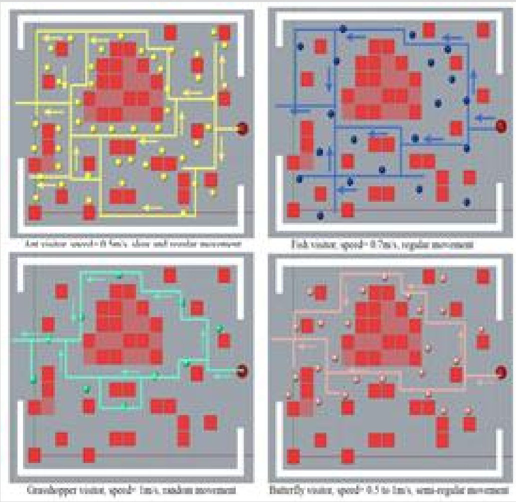


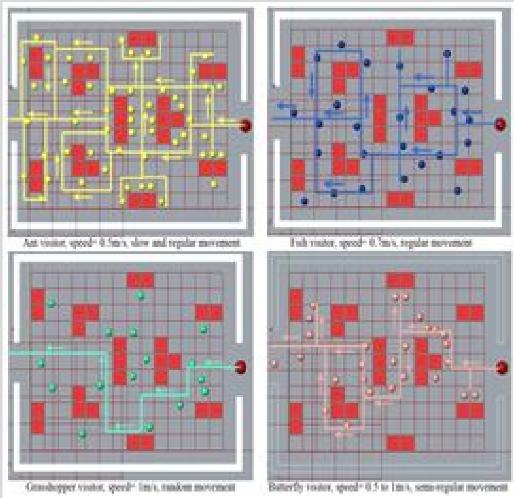
View 360° from different points along the path.

<table>
<tr><td rowspan="7">Script D</td><td colspan="2">Swarm Intelligence
Simulating physical bodies moving randomly with a global force.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>During the simulation some errors occurred.</td><td>During the simulation some errors occurred.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Feedback to Generation stage and change some exhibit locations in the error locations.</td><td>Feedback to Generation stage and change some exhibit locations in the error locations.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Some exhibits are moved from the circulation path to facilitate movement.</td><td>Some exhibits are moved from the circulation path to facilitate movement and other exhibits are added.</td></tr>
</table>

A Simulation by visitor's styles has been made.	A Simulation by visitor's styles has been made.



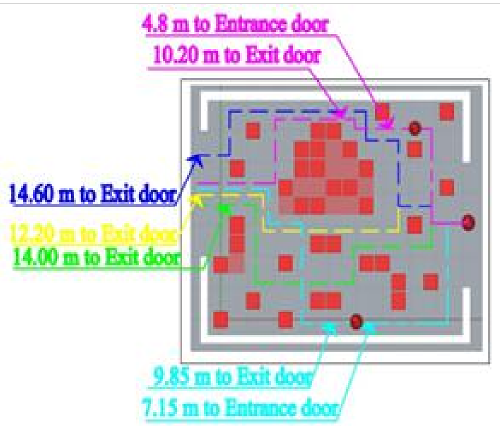


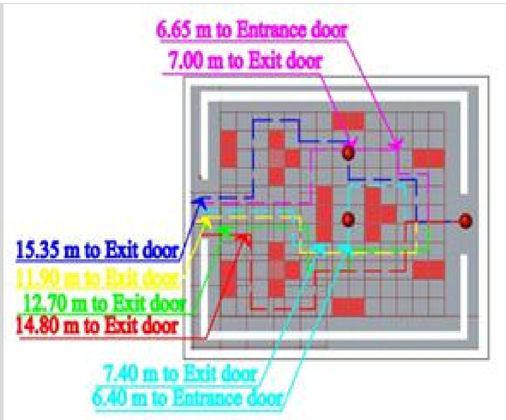


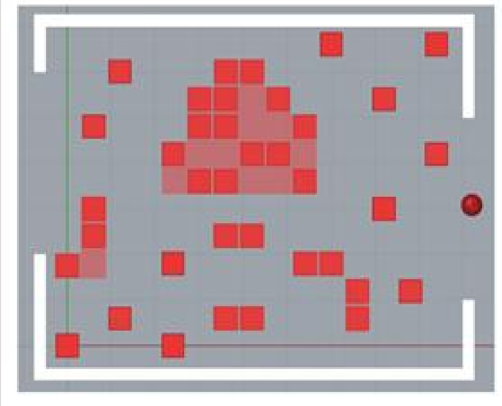
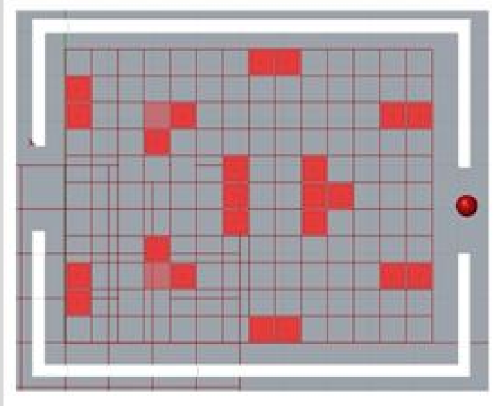
In order to check the effect of the exhibits arrangement on the visitor's movement.	In order to check the effect of the exhibits arrangement on the visitor's movement.

A*

Studying exit point and its distance from any point in the hall.





	Distances are less than 15.00m from any point inside the hall to the Entrance and Exit doors.	Distances are less than 15.00m from any point inside the hall to the Entrance and Exit doors, except one point and its similar on the line. In order to solve such error, two exhibits are removed from the exhibition's pattern.
• **Fourth stage: -The final exhibition area has been presented after the recent modifications.**		
Exhibition area	 Hall A	 Hall B

D. Results

- A large number of design alternatives are generated for the same hall.
- The selected alternatives will be tested, in order to check its conformity to the museum hall arrangement rules, until the most suitable alternative is selected.
- According to the personal territory and how it could affect the other visitor's ability to see most of the exhibits during their visit, some precautions have been taken into consideration during the design stage.
- Despite the unpredictable movement, according to visitor's behavior styles, an easy and safe circulation has been checked, for each style of movement.

Conclusion

- **Museum Cultural Message.**

Museums are documenting cultural events and ideologies. They are exhibiting culture in the first place, and the hidden message behind this exhibition is the main concern of any museum. This message is delivered to each of the museum visitors through a different type of experiences, as shown in figure (C.1), depending on the Exhibits types, which should be selected and displayed in a manner of different visitor's interest, in accordance with the museum space design, taking into account the different characteristics that control the visitor's behavior.

The main concern of museum curators is the visitor's impressions about the museum, and how people respond, and interactions to museum displays. Museums have always been able to stimulate the visitor's curiosity, and to do so, artifacts should be exhibited with different arrangement philosophy, depending on offering knowledge in a simple and attracting way. Ideologically, Museum is an expressive institution rather than an interpretive one, as it presents different kind of knowledge presentation for the biological and social or cultural anthropology.

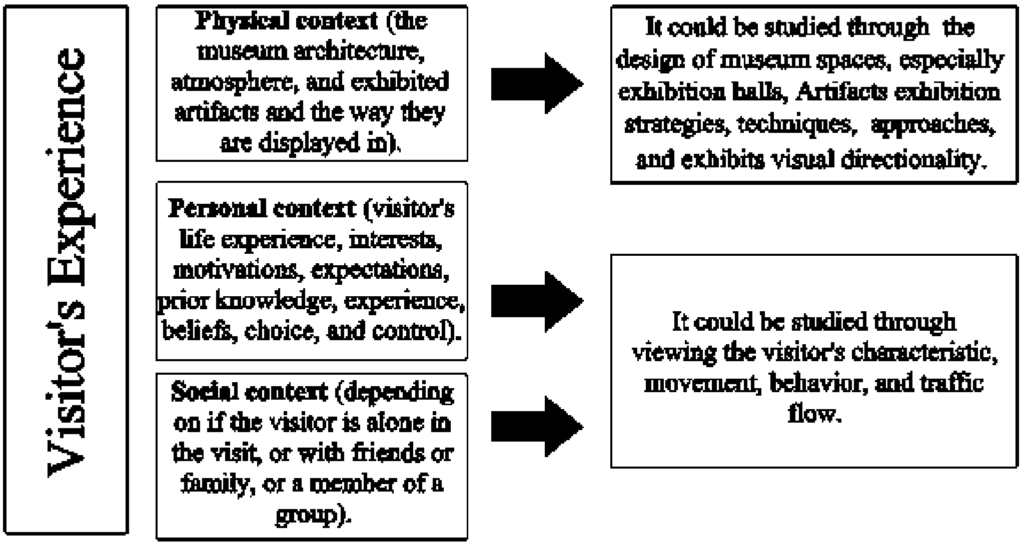


Figure C.1 Visitor's Experience
Source: Done by the researcher.

Exhibits should be displayed in context, according to certain exhibition technique and approach, supported with its original cultural background insights, in order to give an impression of the dynamics of the cultures represented.

In exhibition design, the designer has to develop the exhibition techniques in order to merge between the visual, auditory, and physical exhibition, in order to get the targeted interaction between visitors and exhibits, in accordance with the following:

- Museum type (historical, artistic, science…etc.) & size (big, medium, small).
- Museum design (the museum plan design including the relation between spaces in the same zone, and the relation between the museum zones).
- The cultural and educational message the museum presents.
- The exhibition hall shape.
- The exhibited pieces type

This encourages the museum visitors to build their understanding of cultures on what they get through their visit. Accordingly, when a museum represents a prejudices in the cultures, it renders the story in a different way; in addition it interprets, and seeks to convey visitors with its ideology.

It has been noticed that the exhibition design has an interrelated influence with the visitor's movement. Because of that, the exhibits arrangement, and the visitor's behavior inside halls should be taken into consideration in the museum halls design. Due to the differences between museum visitors in (age – educational background - culture…etc.); their movement are different inside halls. Each visitor has his own interest that controls his direction, and consequently his velocity. Because of that, there are four movement behavioral styles for visitor's movement inside the museum (Ant – Butterfly – Grasshopper – Fish). Each type has a different movement style, so to control their movement, there are many design strategies could be followed. These strategies will definitely affect the visitor's traffic flow inside the hall.

In the light of that, the designer has to study the human behavior and interest inside the museum halls, in addition, to another study for the ways to facilitate the visitor's movement to see most of the exhibited pieces.

- **The Digital Design of Museums.**

Concerning the new digital technology, it became the dominant concept in many fields for a while. In the field of museum design, this technology was limited on museum architecture, exhibits documentation, monitoring, and controlling all museum spaces in the last decades. Recently, the museum design has become more advanced by utilizing this digital technology, as it has been applied in other design aspects regarding the museum exhibition design, and visitor's interactions.

With regard to exhibition design, many museums have implemented this digital technology to the exhibits itself, using complicated computer programs to introduce the museum message in a different way to facilitate the visitor's experience getting, through presenting an unforgettable experience in many fields, and rising the passion of learning about the history, and inventions, depending on visitors interactions with exhibits.

The exhibition designers made use of this technology in creating a digital Diorama system for the exhibits, in accordance with the exhibits type, available data such as movie scenes, and the museum space. The utilization of digital technology has been extended beyond this, to create an interactive digital museum design, based on navigation system and interactive data using touching screen.

Before implementing this technology in the exhibition design, the visitor's behavior and movements were adopted and predicted by the designer. Nowadays, with the help of this technology, the study of visitor's interactions with the exhibited pieces became easier.

- **Architectural design by Algorithms.**

During the recent decades, new digital design methods and generative tools have taken their place in the field of architecture utilized by the computer as a design tool. Technological architecture is being replaced by computational architecture including topological, non-Euclidean geometric space, kinetic and dynamic systems, and genetic algorithms. The challenging was not only "*What we are designing?*", but also "*How we design?*".

In addition, new forms and functional solutions had been generated in the last decades, as integration between many fields of science. This integration had occurred due to the relation between form geometries and mathematical equations, which became more common after using algorithm in the field of architectural design.

In the field of architecture, algorithms had become more effective, according to its ability to produce an infinite number of solutions for many design problems, which presents the emergence of biological paradigm in the architectural design, based on simulating life creatures. In the computational architecture, algorithms could be applied nearly in the main design aspects, as shown in figure (C.2).

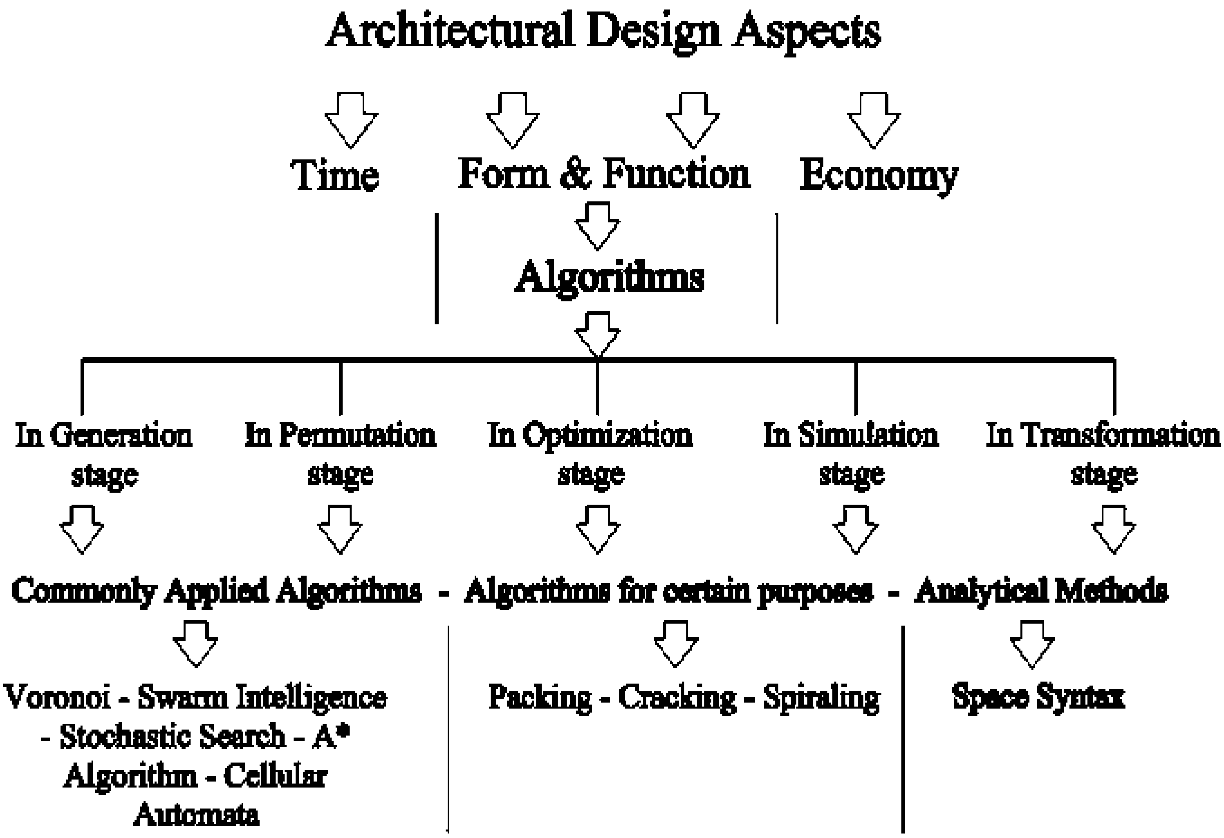


Figure C.2 Architectural design by Algorithms
Source: Done by the researcher.

Accordingly, Algorithmic design methodology has become the main dominance digital design trend nowadays, which stresses on the necessity to improve and expanse its applications in the field of architectural design for many buildings that leads to study the advantages on the design in comparative with its consequences, as shown in table (C.1).

Table C.1 Advantages and Disadvantages of utilizing Algorithms in the Architectural design[1].

Advantages	Disadvantages
• It is a very simple and common generative design tool, as it is the base script for all digital design programs, supported with a simple platform, which make the designer has a superficial knowledge with computer design programs could deal with.	• The architect has to study more about computer programing and software design field, which is a way of his concern, in order to be aware more about what he is going to deal with.
• It is a perfect way to get an infinite no. of design solution, and generate impressive and different forms, every time the algorithm is operated.	• The key concept of this process is the architect ability to define the design problem precisely, and then choose carefully the proper algorithm for the highlighted design problem.
• There is a huge no. of algorithms could be used in the architectural design, which give the architect the ability to choose the simplest algorithm to do the job, in a very short time.	• In many times the architect has to write a specific algorithm, to solve a certain design problem.
• Solving design problems by Algorithms is about using one or more algorithms at the same time, in order to get a proper design solution for the defined problem, which mean that the algorithm will work in two different directions in the design favor (one is to get the solution, and the other is to evaluate the generated solution and check if it conform with the design rules or not).	• In many design problems, the architect has to use more than one algorithm to solve a certain problem, and define more rules, in order to get a proper solution for the problem, which takes a long time to solve a certain problem in the initial design stage.
• The architect role during this algorithmic design process could not be neglected, he is the only one how can define precisely the design concept, rules, and direct the algorithm to the targeted design. He is the main design coordinator, and controller, which make the algorithm work for the architect and design favor.	• Sometimes the architect has to deal directly to the design problem with his own knowledge of the architectural design aspects, standards, and design constrains related to society rules and regulations.
• Algorithms as a generative design tool, is always in such a need to be developed to fulfill the architects imagination, which works in the design product favor.	• In accordance with the rapid development in the commputer technology, algorithms are in a daily development, which requires that the architect has to keep on going with the new developments in this field.

[1] Done by the Researcher.

- **Exhibition Design by Algorithms.**

It was found that algorithms could be applied in the design of museums, especially on the Exhibition halls design. Accordingly, a digital design methodology had been introduced, similar to the common design methodology, in order to demonstrate the effect of utilizing algorithms on the exhibition halls design, which could be concluded in table (C.2). Based on this methodology an application had been made; to prove the validation reliability of this methodology, through which a study for new exhibition design way using Swarm intelligence, and Cellular Automata algorithms, and its effect on the visitor's behavior Space Syntax theory. The design of the exhibition hall is subject to some parameters, used as inputs to generate a new digital solution for the hall arrangement easily, and evaluates it until the most suitable solution is selected.

Table C.2 Manual Design VS. Digital Design[1].

Stages	Manual Exhibition Design	Algorithmic Exhibition Design
• **First stage**	**Decision Making** Museum type, size, types of exhibited artifacts & its size, and consequently the Museum Cultural Message. **Done by:** Designer	
• **Second stage**	**Exhibits arrangement** - According to certain rules for exhibits arrangement, exhibits are located in their locations. - Exhibits are presented visually, by sketches or software. **Done by:** Designer	**Exhibits arrangement** - Exhibits are arranged Randomly or according to certain rules - Exhibits are presented digitally using software in 2D and 3D. **Done by:** Software
• **Third stage**	**Visitor's Behavior observation** - Visitor's behavior and movement are predicted by designer. - The exhibits arrangement is updated according to the expected movement paths, and predicted points to have movement obstacles. **Done by:** Designer	**Visitor's behavior Simulation** - A simulation for the Visitor's behavior and movement will be made depending on the inputted visitor's movement styles; the software will generate an infinite no. of paths for each movement style the design add. - The software will recognize an error in many cases, which leads back to the exhibits arrangement. - The software will not stop until no error appears. - The exhibits arrangement is updated every time the software gets an error, until no errors. **Done by:** Software
• **Fourth stage**	**Final design** The final design is reached manually, and then exhibits could	**Final design** The final design is generated digitally, and then exhibits could be placed in their

[1] Done by the Researcher.

	be placed in their location in the museum hall.	location in the museum hall.
• **Advantages**	1. The exhibition designer will be more flexible in dealing with these special pieces of art. 2. The designer artistic sense will work for design benefit. 3. The museum culture message will be more obvious with this design methodology.	1. This design method provides more flexibility to make changes easily to the generated arrangement design alternatives at any stage of the design. 2. An infinite number of alternatives have been generated to arrange exhibits inside one hall. In addition, the selected alternative will be tested, in order to check its compatibility with the museum hall arrangement rules. 3. According to the personal territory and how it could affect the other visitor's ability to see most of the exhibits during their visit, some precautions have been taken into consideration during the design stage. 4. Although the unpredictable movement, according to visitor's behavior styles, an easy and safe circulation has been checked during the visit inside the hall. 5. The presented design methodology is valid and reliable, but at the same time it needs more development.
• **Disadvantages**	1. The design is based on the designer imagination to decide the exhibits location. 2. The study of visitor's movement is subject to the designer predictions, which affects the design itself, when the visitor's movement is unpredictable. 3. It will be very hard for the designer to deal with the visitor's perception and interests, if the exhibits have the same height.	1. The proposed methodology and software is subject to the ability of the designer to deal with, and defining correctly the arrangement rules software should follow. 2. In case the exhibits have different dimensions, more rules should be added, the methodology will be the same, but some changes will take place in the evaluation stage. 3. It needs more practice and work from the designer, to get benefit of this software. 4. The designer has to add more rules during the generation and permutation stage in order to define the museum culture message precisely.

- **Results.**

The main objective of the research was to determine the effect of utilizing the Algorithmic design methodology in the architectural design of museum buildings, especially in the exhibition hall arrangement and the visitor's behavior, accordingly the research results are as follows:

- The concept and process of museum design should be adopted, and introduced in advance by the architect; in that case, the use of new design methods will become effective.
- Following this digital methodology strengthens the chance of applying such design technology in the upcoming museum design, and it could be utilized also on renovated museums.
- With regard to the proposed automated design methodology, it is a Performance based design methodology that caters for the design performance more than the design result, which could be developed in the future to a Rule based design methodology, by adding more rules and design constrains in all the design stages, in order to get the targeted design.
- In both manual exhibition design and the automated design, the main design evolver and controller is the museum cultural message.
- New museum design solutions are introduced, and evaluated with the help of algorithmic generative design tools.
- New generation of design tools will be more featured in the upcoming years, as a result of the continuing development in the computational design methods.
- Although algorithms are applied in the design of many building types, it is rarely used in the design of museum buildings.
- Regarding museum design and the utilization of new digital technologies, many museums around the world made use of this new trend especially in exhibition design, but the utilization of algorithm is a new world, which the designers has to decide if it will be useful in the exhibition design.
- Regarding the concept of museums around the world, the concept of museums became very common nowadays, consequently, many types of museums has be introduced in many countries such as in USA 17,500 Museum, In UK 1600 Museum, In Israel 64 Museum, Japan over than 500 Museums. With regard to the museum concept in Egypt, it is considered receded, and neglected, which give rise of supporting and developing the museum concept. The Government should care more about establishing new museums, in different branches of knowledge, (In Egypt 50 Museum). Museum Cultural and Educational rule awareness should be adopted by the Government first, and support it through social media for adults, and in the Basic educational stages.

Recommendations

I. **Regarding the exhibition halls design**.
The designer should care more about visitor's behavior inside the hall, and their interactions with the exhibited artifacts, in the light of the museum cultural message.

II. **In implementing digital design techniques in the architectural design**.
The designer should focus on generating proper functional solutions, as much as generating new form.

III. **In utilizing algorithms in the architecture design of museums**.
The designer should follow certain methodology, according to the main purpose of this utilization (Form or Function), in addition to select the appropriate algorithm to achieve this design.

IV. **In utilizing algorithms in the exhibition hall design**.
The previously discussed methodology needs more development to be generalized for all museums, as some changes may take place in accordance with the museum type.

V. **Further studies.**

- <u>Architectural design.</u>
  The utilization of algorithms should include also the other design aspects (Economy & Time management).
- <u>Virtual Museums.</u>
  Studying the virtual museum visitors as it needs more development due to the spread of the virtual museums.
- <u>Museum spaces.</u>
  The utilization of algorithms in the design of museums needs more development regarding the indoor quality (lighting systems, ventilation systems…etc.).

References

• English References.

• Books

1. Al Daffa', Ali Abdullah, "The Muslim contribution to Mathematics", Croom Helm, London, 1977, P (13-44).
2. Aranda. B, Lasch. C, "*Pamphlet Architecture 27: Tooling*", Princeton Architectural press, New York, 2006, P (10-52).
3. Atsuyuki, O, Boots, B, Sugihara, K, Nok Chiu, S, "*Spatial Tessellations – Concepts and Applications of Voronoi Diagrams*", 2nd edition, John Wiley, 2000, P (6 – 70).
4. Aurenhammer, F. and Klein, R, "Ch. 5-Voronoi Diagrams." Of "*Handbook of Computational Geometry*" Amsterdam, Netherlands: North-Holland, 2000, P (201-290).
5. Bentley, P, "*Evolutionary Design by Computers*", 1999, P (1-20).
6. Burry. J & M, "*The New Mathematics of Architecture*", Thames & Hudson Ltd, 2012, P (87-137).
7. Chiara, J, Callender, J, "Time-Saver standards for building types", McGraw-Hill international editions, USA, 2nd edition, 1987, P (339-375).
8. Computing Studies Syllabuses , "*Methods of Algorithm Description*", 2nd edition, Board of Studies, NSW, Australia, 1995.
9. Dean. D, "*Museum Exhibition - Theory and Practice*", Routledge – London and New York, 1994 – 1996, P (44 - 56).
10. Desvallées. A and Mairesse. F, "*Key Concepts of Museology*", The Musée Royal de Mariemont and ICOM, 2010.
11. Falk. J and Dierking. L., "*The Museum Experience*", 1992.
12. Freeman. C, "*The Horses of St. Mark's: A Story of Triumph in Byzantium, Paris, and Venice*", The Overlook press, NewYork, 2004.
13. G.Ellis Buracw, "*Introduction to Museum work*", Third edition, Altamira press, 1997, P (133).
14. H.H, B.C, "*The New Encyclopaedia, Macropaedia*", Chicago, 1983, volume12, P (657-660).
15. Hillier. B, "*Space is the Machine: a configurational theory of architecture*", Cambridge University Press, Cambridge, 1996, P (138-165).
16. Impey. O.R., and MacGregor. A., "*The origins of museums: the cabinet of curiosities in sixteenth and seventeenth century Europe*", House of Stratus, London, 2001.
17. Judea, Pearl, "*Heuristics: intelligent search strategies for computer problem solving*", Addison-Wesley Longman Publishing Co, 1984.
18. Khabazi, Z., "*Generative Algorithms using Grasshopper*", Morphogenesism, P (2-4).
19. Kliment, S.A, "*Building type Basics for museums*", John Wiley and sons, New York, 2001.
20. Kunstverlag. D, "*The Baroque Treasury at the Grünes Gewölbe Dresden*", 1st Ed. Munich - Deutscher Kunstverlag, 2007.
21. Longman Dictionary of Contemporary English.
22. Lord G, D and Lord B, "*The Manual of Museum Planning*", Grown copy right, HMSO for publication, London, 1991, P. (115-116).
23. Mark de Berg, Marc van Kreveld, Overmars, M, Schwarzkopf, O , "*Computational Geometry*", 3rd edition, Springer-Verlag, Berlin Heidelberg, 2008, P (148 – 167).
24. Morgan, C. H. "*The Life of Michelangelo*", Reynal and Company, New York, 1966, P (209–211).

25. Penna, William & others, “*Problem seeking, an architectural programing primer*”, AIA press, 1987, P (36).
26. Schneider, M. and J. Gersting, “*An Invitation to Computer Science”*, West Publishing Company, New York, 1995, P (9).
27. Sipser, M., “*Introduction to the theory of computation*”, Second edition, Thomson Course Technology, Massachusetts, USA, 2006, p1-2.
28. Spall, J. C, “*Introduction to Stochastic Search and Optimization – Estimation, Simulation, and Control*”, Wiley, 2003, P (1 - 30).
29. Wolfram, S, “*A new kind of science*”, Wolfram Eropean search limited, 2002, P (180).

• Thesis

1. Abd El Rehem, M. M, “*Museums and Architecture*”, M.Sc, Faculty of Engineering, Cairo University, 2005.
2. Buus, D.P, “*Constructing Human-Like Architecture with Swarm Intelligence*”, M.Sc, Department of Computer Science, Aalborg University, Denmark, August 2006, P (13-55).
3. El Daly, H. M. “*Revisiting algorithms in architectural design: towards new computational methods*”, Phd, Ain shams university, Department of Architecture, 2009, P (115 – 120).
4. Kotnik, T., “*Algorithmic Extension of Architecture*”, Swiss Federal Institute of Technology, Zurich, October 2006, P (17-89).
5. Larsen, N.M, “*Generative Algorithmic Techniques For Architectural Design*”, Phd, Aarhus School of Architecture, Denmark, July 2012.
6. Mohammed, A. A, “*Spatial Conditions For Sustainable Communities: The Case of Informal Settlements in GCR*”, M.SC, Ain Shams University, Faculty of Engineering, Department of Urban Planning, Cairo, Egypt, 2010.
7. Zitzler. E, “*Evolutionary Algorithms for Multi-objective Optimization: Methods and Applications*”, Phd, Swiss Federal Institute of Technology Zurich, Germany, 1999, P (19-107).

• Papers

1. Achten,H, and Joosen, G, “*The Digital Design Process: Reflections on a Single Design Case*”, *Eindhoven University of Technology, The Netherlands.*
2. Antoniou. A & Lepouras. G, “*Adaptation to Visitors’ Visiting and Cognitive Style*”, University of Peloponnese, Department of Computer Science and Technology, P (1-2).
3. Batty. M, Rana. S, “*Reformulating space syntax: The automatic definition and generation of axial lines and axial maps*”, Center for Advanced Spatial Analysis (CASA), University College London, London, 2002.
4. Bentley. P, “*Aspects of Evolutionary Design by Computers*”, Intelligent Systems Group, Department of Computer Science, University College London, London.
5. Cardoso. D, “*Controlled unpredictability: Constraining Stochastic Search as a Form-Finding Method for Architectural Design*”, Department of Architecture, Computation Group Massachusetts Institute of Technology, May 2006.
6. Carranza. P. M, Coates. P, “*The use of Swarm Intelligence to generate architectural form*”, CECA University of East London, Stratford, London.
7. Clarke, C and Anzalone, P, “*Architectural Applications of Complex Adaptive Systems*”, proceedings of ACADIA Conference, 2003.
8. Cui. X, “*Swarm Intelligence, Bio-inspired Emergent Intelligence*”, Oak Ridge National

Laboratory, U. S. Department of Energy.
9. Delling. D, Sanders. P, Schultes. D, Wagner. D, "*Engineering Route Planning Algorithms*", Springer, 2009.
10. Duffy, D.E, and Quiroz, A. J, "*A Permutation Based Algorithm for Block Clustering*", Journal of Classification, Volume 8, 1991.
11. Eleftheria. F, "*Genetic Algorithms in Architecture: A Necessity or a Trend?*", Department of Architecture, Massachusetts Institute of Technology.
12. Erneholm. C. O, "*Simulation of the Flocking Behavior of Birds with the Bodies Algorithm*", School of Computer Science and Communication, Royal Institute of Technology, Stockholm, Sweden, 2011.
13. Garnier. S, Gautrais. J and Theraulaz. G, "*The biological principles of swarm intelligence*", Springer Science - Business Media, July 2007.
14. Gross, Mark D, "*FormWriter - A little programing language for generating three dimensional form Algorithmically*", CAAD futures, 2001, P (577-578).
15. Gurevich, Y, "*The universal Turing machine – A half century survey*", edited by Herken, R, Springer – Verlag wien, New York, 1995, P (377).
16. Henery, C. "*How Visitors Relate to Museum Experience: An Analysis of Positive and Negative Reactions*", Journal of Aesthetic education, vol. 34, No.2, Board of Trustees of the University of Illinois, 2000.
17. Hillier. B& Iida. S, "*Network and psychological effects in urban movement, Proceedings of Spatial Information Theory: International*", Springer, New York, 2005.
18. Hillier. B, Al. P, Ratti. C, "*Environment and Planning B: Planning & Design*", 2004.
19. Judea, & Pearl, "*Generalized best-first search strategies and the optimality of A**", Journal of the ACM, 1985.
20. Kaynar. I., "Visibility, movement paths and preferences in open plan museum", University of Michigan, USA.
21. Kevin D. Fisher, "*Placing social interaction: An integrative approach to analyzing past built environments*", Journal of Anthropological Archaeology, El Sevier, Volume 28, Issue 4, December 2009.
22. Kolarevic. B, "*Designing and Manufacturing Architecture in the Digital Age*", University of Pennsylvania, USA.
23. Krawczyk, R. J, "*Architectural Interpretation of Cellular Automata*", College of Architecture, Illinois Institute of Technology, Chicago, IL, USA, 2002.
24. Li.Li, "*The optimization of architectural shape based on Genetic Algorithm*", Frontiers of Architectural Research, 2012.
25. LIM, C.K, "*A Revolution Of The Design Process*", National Chiao Tung University, Taiwan.
26. Lim, Chor-Kheng, "*A Revolution of the Design Process*", Caddria, 2004.
27. Mancas. M, Glowinski. D and others, "*Hypersocial Museum: Addressing The Social Interaction Challenge With Museum Scenarios And Attention-Based Approaches*", QPSR of the numediart research program, Vol. 2, No. 3, September 2009.
28. Michal. G. K, Houck. C. R, Joins. J. A, "*A Genetic Algorithm for Function Optimization: A Matlab Implementation*", North Carolina state university, The National science foundation, 1996, P (2).
29. Milena, S & Ognen, M, "*Application of Generative Algorithms in Architectural Design*", Graz University of Technology, Austria.
30. Oppermann, R., & Specht, M, "*A Context- sensitive Nomadic Information System as an*

Exhibition Guide", German National Research Center for Information Technology, 2000.

31. Peak, W, Messinger, Mott, "*Evidence for complex, collective dynamics and emergent, distributed computation in plants*", proceedings of the National Institute of Science of the USA, USA, 2004.
32. Ratti. C, "*Space Syntax: some inconsistencies, Environment and Planning B: Planning & Design*", 2004.
33. Sookhanaphibarn. K & Thawonmas. R, "*A Movement Data Analysis and Synthesis Tool for Museum Visitors' Behaviors*", Intelligent Computer Entertainment Laboratory, Department of Human and Computer Intelligence, Ritsumeikan University, Japan, P (145 – 151).
34. Terzidis. K, "*Algorithmic Architecture*", Architectural Press, Elsevier, 2006, P (38 - 103).
35. Tzortzi. K, "*Museum Building Design And Exhibition Layout: Patterns of Interaction*", Proceedings of 6th International Space Syntax Symposium, İstanbul, 2007.
36. Vaughan. L, "*The spatial syntax of urban segregation*", published research paper, Bartlett School of Graduate Studies, UCL, London.
37. Wu, J.C, and Wei, M. H, "*Design of an Optimal Benes WEX Architecture Based on Sufficient Permutations*", PIERS Proceedings, Taipei, 2013.
38. Zabinsky. Z. B, "*Stochastic adaptive search for global optimization*", University of Washington, Seattle, Washington, USA, P (20).

- **Articles**

1. Lewiss, G, "Types of museums", Encyclopedia Britannica.
2. Lewiss.G, "The history of museums", Encyclopedia Britannica.
3. Miller. P, "*Swarm Theory*", National Geographic Magazine, July 2007.

- **Conferences**

1. ICOM, International Council of Museums, 21st General conference in Vienna, Austria, 2007

- **Discussions**

1. Smit. R. MA, "*Rethinking Museums from a Visitor's Perspective*", Discussion on Museum Experience, 2013.

- **Lectures**

1. G. Donald Allen, "Islamic Mathematics and Mathematicians", Master's degree online lecture, Department of Mathematics, Texas A&M University, 27 June 2007.
2. Sarvottamananda, S, "*Voronoi Diagrams*", Ramakrishna Mission Vivekananda University, BHU-IGGA, 2010.

- **Requirments**

1. Lundholm Associates Architects "*Art gallery of Saskatchewan – Functional program*", Toronto, Canada,27 April 2010, P (3-2).
2. Peng, H and Archer, F, Arup AGU, unpublished project description.

- **Reports**

1. "*UCL SPACE SYNTAX SOFTWARE MANUALS, AXMAN, ORANGEBOX, NETBOX, NEWWAVE, PESH and SPACEBOX*", THE BUNDLE, July 2004.
2. Glasgow. A.H. J, "*Swarm Intelligence: Concepts, Models and application – Technical report*", School of Computing Queen's University, Kingston, Ontario, Canada, February

2012.
3. Heneghan.Peng architects, ARUP, Buro Happold JV "*GEM Pre-Schematic Design Report*", April 2004.
4. METAPHOR JV, "*GEM, Circulation and Wayfinding Schematic Design*", November 2004.

• World Wide Web

1. A star, theory.stanford.edu/~amitp/GameProgramming/AStarComparison.html
2. Al Raha Development, www.fosterandpartners.com/projects/al-raha-beach-development/
3. Chengdu Museum, www.e-architect.co.uk/china/chengdu_museum.htm
4. Denver Museum, www.arcspace.com/architects/Libeskind/denver2/denver2.html
5. Depth map software, www.spacesyntax.net/software/ucl-depthmap/
6. Dresden palace – Germany, www.dresden.de/dig/en/sightseeing/sehenswuerdigkeiten/historische_altstadt/residenzschloss.php
7. Dynamic Museum, www.unstudio.com/projects/the-museum-of-middle-eastern-modern-art-momema
8. Egyptian Museum and Papyrus Collection, Berlin www.egyptian-museum-berlin.com/c01.php
9. Game of life, www.bitstorm.org/gameoflife/
10. Glasgow Museum of Transport, www.glasgowarchitecture.co.uk/museum-of-transport-glasgow
11. Guggenheim Bilbao Museum, www.guggenheim.org/bilbao
12. Guggenheim Museum, Abu Dhabi, www.guggenheim.org/abu-dhabi
13. Imperial War Museum, openbuildings.com/buildings/imperial-war-museum-profile-9858
14. Jewish Museum, www.archdaily.com/91273/ad-classics-jewish-museum-berlin-daniel-libeskind/
15. KAUST Museum of Science and Technology in Islam, museum.kaust.edu.sa/
16. MAXXI – National Museum of the 21st Century Arts, www.zaha-hadid.com/architecture/maxxi/
17. Museum of modern art, New York www.e-architect.co.uk/new-york/moma-new-york
18. New Louver Museum, www.designbuild-network.com/projects/louvre-abu-dhabi/louvre-abu-dhabi4.html
19. Nubian Museum, www.numibia.net/nubia/outdoor.htm
20. Online Etymology Dictionary,

www.etymonline.com/index.php?term=muse&allowed_in_frame=0
21. Porsche Museum,
www.porsche.com/international/aboutporsche/porschemuseum/theproject/architecture/
22. Salah El Din citadel,
www.cairocitadel.gov.eg/egypt_in_mohali_A.html
23. Swarm Inteligence,
IAAC / Digital Technologies in Architecture / 2007: swarm intelligence/
24. The American natural history Museum,
www.amnh.org/
25. The Ashmolean Museum,
www.ashmolean.org/
26. The British Museum in London,
www.britishmuseum.org/visiting.aspx, moodemapcollector.blogspot.com/2011/08/plan-of-british-museum-1894.html, www.spacesyntax.com/project/british-museum/ and www.spacesyntax.com/project/royal-academy-of-arts/
27. The central armed force museum,
www.moscow.info/museums/central-armed-forces-museum.aspx
28. The Charleston Museum,
www.charlestonmuseum.org/about
29. The Children Museum,
www.childrensmuseums.org/index.php/professional-development.html
30. The Deutsches Museum,
www.deutsches-museum.de/en/information/museum-courtyard/
31. The Egyptian museum,
www.sca-egypt.org/eng/MUS_Egyptian_Museum.htm
32. The Grand Egyptian museum,
www.hparc.com/work/the-grand-egyptian-museum/ , www.gem.gov.eg/
33. The Green Vault,
atlasobscura.herokuapp.com/places/green-vault and www.skd.museum/en/museums-institutions/residenzschloss/gruenes-gewoelbe/index.html
34. The Guggenheim Museum,
www.greatbuildings.com/cgi-bin/gbi.cgi/Guggenheim_Museum.html/cid_cr1037_b.html and www.guggenheim.org/new-york/about/guggenheim-images
35. The Louvre Palace,
www.louvre.fr/
36. The Metropolitan Museum,
www.metmuseum.org/visit
37. The Museum of disability history, New York
museumofdisability.org/information/about-us/
38. The Museum of Disability,
museumofdisability.org/
39. The National Museum of Western Art,
www.nmwa.go.jp/en/
40. The Story Hall,
www.adonline.id.au/buildings/storey-hall/
41. The Water Cube,
www.ptw.com.au/ptw.php

42. The Winter Palace,
www.saint-petersburg.com/museums/hermitage-museum/
43. Vilnius Guggenheim Hermitage Museum,
www.designbuild-network.com/projects/guggenheimvilnius/
44. Voronoi cells,
object-e.net/uncategorized/algorithmicbody
45. Voronoi diagram,
neoarchbeta.wordpress.com/2011/05/07/voronoi-diagramsnature-and-architecture/
46. Voronoi diagram,
mathworld.wolfram.com/VoronoiDiagram.html
47. Waterford Medieval Museum, Ireland.
www.archdaily.com/487908/medieval-museum-in-waterford-rojo-studio-architects/

• المراجع العربية

• الكتب

1. البستانى، بطرس ، القطر المحيط، بيروت، لبنان،1956،ص171
2. خلوصى ، محمد ماجد، أحمد أيمن, "الموسوعة المعمارية – المتاحف – الجزء الأول"، 2004، ص16-17
3. زهدى، بشير ، "المتاحف – دراسات ونصوص قديمة"، منشورات وزارة الثقافة فى الجمهورية العربية السورية، دمشق 1988، ص(65-111).
4. فيليب، آدامز وآخرون، "دليل تنظيم المتاحف- إرشادات عملية"، ترجمة.د.محمد حسن عبد الرحمن، الهيئة العامة للكتاب، 1993، ص 11

• الرسائل

1. راشد ، هيثم فاروق ، "دور الواقع الإفتراضى فى تصميم المتاحف"، رسالة ماجستير، كلية الهندسة جامعة القاهرة، أكتوبر 2004
2. صلاح الدين، خالد ، "عمارة المتاحف"، رسالة ماجستير، كلية الفنون الجميلة، جامعة حلوان، 1998
3. عاصم، أيمن, "إدراك الفكر التصميمى للإتجاهات المعاصرة فى عمارة المتاحف"، رسالة ماجستير، كلية الهندسة ، جامعة عين شمس،2007

جامعة عين شمس
كلية الهندسة
قسم الهندسة المعمارية

تطبيق إستخدام الخوارزمات فى تصميم المتاحف

رسالة مقدمة من

نوران خالد سيد مرسى
بكالوريوس الهندسة المعمارية – ٢٠١٠ – جامعة عين شمس

قدمت الرسالة كجزء من متطلبات الحصول على درجة الماجستير فى العلوم الهندسية

تحت إشراف

أ.د/ ياسر محمد منصور
أستاذ العمارة والتحكم البيئى
كلية الهندسة - جامعة عين شمس

د/ حازم محمد الدالى
مدرس مساعد – قسم الهندسة المعمارية
كلية الهندسة - جامعة عين شمس

القاهرة – جمهورية مصر العربية
٢٠١٤

جامعة عين شمس
كلية الهندسة
قسم الهندسة المعمارية

أسم الباحث: نوران خالد سيد مرسى
عنوان الرسالة: تطبيق إستخدام الخوارزمات فى تصميم المتاحف
الدرجة: ماجستير في العمارة

لجنة الحكم والمناقشة:

أ.د/ أحمد فريد جمال الدين حمزة **التوقيع**
أستاذ - رئيس قسم الهندسة المعمارية
كلية الهندسة بشبرا – جامعة بنها

أ.د/ شيماء محمد كامل **التوقيع**
أستاذ العمارة
كلية الهندسة – جامعة عين شمس

أ.د/ ياسر محمد منصور **التوقيع**
أستاذ العمارة والتحكم البيئى
كلية الهندسة – جامعة عين شمس

الدراسات العليا:

موافقة **الختم**
التاريخ: / /

موافقة مجلس الكلية **موافقة مجلس الجامعة**

التاريخ: / / **التاريخ:** / /

إقرار

هذا البحث مقدم إلى جامعة عين شمس، للحصول على درجة الماجستير فى العلوم الهندسية. تم إنجاز هذا لابحث بقسم الهندسة المعمارية – كلية الهندسة جامعة عين شمس فى الفترة من ٢٠١١ – ٢٠١٤.

وقد تم إجراء هذا العمل الذى تحتويه الرسالة بمعرفة الباحث بقسم العمارة – كلية الهندسة – جامعة عين شمس. هذا ولم يتم تقديم هذا البحث أو أى جزء منه لنيل أى مؤهل أو درجة علمية من أى كلية أو جامعة أو معهدعلمى آخر.

وهذا إقرار منى بذلك،،،

التاريخ: / /
التوقيع:
الإسم:
الكلية: كلية الهندسة - جامعة عين شمس

مستخلص الرسالة

يهدف البحث إلى إلقاء الضوء على التأثيرات الناتجة عن تطبيق المنهجية التصميمة بإستخدام الخوارزمات على التصميم المعمارى لمبانى المتاحف. وذلك من خلال دراسة التغيرات الحادثة فى حركة الزواركنتيجة للتغيرات التى تطرأ على طريقة توزيع المعروضات داخل قاعات العرض المتحفى، والتى ستتم دراستها وتحليلها بإستخدام إحدى برامج الحاسب الآلى(Rhinoceros program and Grasshopper plug-in)، والتى تعتمد فى تطبيقها على مجموعة من الخوارزمات الشائع إستخدامها فى العمارة مثل (Cellular Automata, Swarm Intelligence)، والتى من شأنها دراسة توزيع المعروضات داخل قاعات العرض المتحفى، ذلك بالإضافة إلى نظرية Space syntax ، و التى يمكن من خلالها دراسة حركة الزوار. بإستخدام تلك التطبيقات فى مراحل التصميم الأولية؛ يمكن للمصمم التوصل إلى حلول مثلى بالنسبة لطريقة العرض المتحفى والتى من شأنها تحقيق رسالة المتحف الثقافية.

الكلمات المفتاحية: المتاحف – الرسالة الثقافية – خبرة الزوار – قاعات العرض – الخوارزمات.

ملخص الرسالة

إن العملية التصميمية تفرض على المصمم التعامل مع العديد من المحددات، ذلك بالإضافة إلى دراسة العناصر المؤثرة على التصميم بغرض الوصول الى تصميم يحقق أفضل النتائج، بإستخدام أدوات متطورة. ونتيجة للتطور السريع والمتطرد لأساليب التصميم المعمارى بإستخدام الحاسب الآلى، وتطبيقاتها؛ أصبح على المعمارى التعامل مع تلك التطبيقات بإستخدام عدة منهجيات تختلف حسب التطبيق المستخدم و إمكانياته، ومن ثم تطوير منهجيته لتتناسب مع التصميم المراد الوصول إليه. مما جعل العملية التصميمية تعتمد فى الأساس على منهجية متطورة، تهدف للحصول على عدد من الحلول، وكذلك المفاضله بينها للوصول لحل مناسب. وبناءً على ذلك، تطورت العملية التصميمية للعديد من المبانى، لتعتمد بشكل جزئى أو كلى فى بعض الأحيان على تطبيقات ومنهجيات وأساليب مختلفة ومتطورة للوصول لمنتج معمارى متكامل. من بين تلك المبانى كانت مبانى المتاحف، والتى أصبح تطوير أساليب التصميم المستخدمة بها، وكذلك دراسة محدداتها وإمكانيتها ضرورة ملحة فى الوقت الحاضر.

وقد عنى هذا البحث بدراسة كيفية إيجاد فكرة تصميمية، تؤكد على مضمون المتحف والهدف منه، لتتضح من خلالها قدرة الزائر على إدراك المحتوى الثقافى والعلمى للمتحف، وهو ما يعد الهدف الرئيسى لآى متحف. وبالتالى فتقع على المصمم مسؤلية دراسة نوع المتحف، وطبيعة المعروضات داخله، هذا إلى جانب دراسة الرسالة الثقافية المطلوب إيضاحها لزوار المتحف، وإكسابهم مجموعة مختلفة من الخبرات ، بالإضافة إلى طبيعة الزوار وسلوكهم داخل هذا النوع من الفراغات؛ والذى من شأنه أن يؤثر على التصميم بالكامل.

يقوم البحث بدراسة أحد الأساليب المتطورة فى التصميم الرقمى بإستخدام الخوارزمات، وتأثير ذلك على التصميم المعمارى لمبانى المتاحف. يركز البحث على إمكانية الوصول إلى منهجية جديدة لتصميم قاعات العرض المتحفى، وكيفية يمكن أن تتطابق تلك المنهجية مع رسالة المتحف الثقافية، بالإضافة إلى دراسة توزيع المعروضات بشكل مختلف وعلاقتة ذلك بحركة الزوار، والتى ستتضح من خلال إحدى التطبيقات الرقمية لتصميم قاعة عرض بإستخدام الخوارزمات.

الفهرس

مقدمة

خلال العقود السابقة، ظهرت مجموعة من أساليب التصميم الرقمية فى مجال التصميم المعمارى والتى تعتمد بشكل أساسى على تكنولوجيا الحاسب الآلى. فى عام ١٩٦٣، اثبت إيفان سيزرلاند أن تكنولوجيا الحاسب الآلى يمكن أن تستخدم فى التصميم المعمارى كأداة لصناعة المجسمات وكذلك إتمام أعمال التصميم. فى القرن العشرين، أصبح من الصعب تخيل المنتج المعمارى النهائى بدون إستخدام تلك التكنولوجيا الرقمية من خلال الحاسب الآلى؛ والتى تلت التطورات التى طرأت بعد Turing Machineعام ١٩٣٦. ظهرت بعد ذلك مجموعة من أساليب التصميم الحديثة، والتى تقدم حلول متطورة للعلاقة بين التصميم إعتماداً على العلاقات الوظيفية والشكل الخارجى للمبنى، وكذلك علاقتهم بالبيئة المحيطة. و من ثم تطورت أساليب التصميم المعمارى بإستخدام الحاسب الآلى، فأصبحت لا تقتصر على برامج CAD، و إنما تشمل أيضاً مجموعة من البرامج تعتمد على إستخدام الأكواد والمخطوطات الرقمية كالخوارزمات. نتيجة لذلك، تم إدراج تلك التكنولوجيا فى مراحل التصميم المختلفة؛ وبالتالى، تغير الفكر المعمارى، وأصبحت عمارة الوقت الحاضر حسابية أو معلوماتية لتحل محل العمارة التكنولجية. وعليه، فقد دعت الحاجة إلى تطوير أساليب إستخدام تلك التكنولوجيا وخاصة الخوارزمات فى جميع مراحل التصميم، بغرض الحصول على حلول تصميمية متطورة، وبالتالى منتج معمارى أفضل. ونتيجة لذلك فقد تأثر تصميم مجموعة من المبانى بهذا التوجه الحسابى، ومن بينها كانت مبانى المتاحف.

طبقا لعلم الأساطير الإغريقية؛ "المتاحف" هى "مجلس الإله"، و "المكان المخصص للإلهام"، و " مكان تجمع الفلاسفة لمناقشة بعض الموضوعات". تطور هذا الفكر خلال عدة القرون إلى أن أصبحت المتاحف عبارة عن مبنى منفصل، يعكس الذوق الفنى، ويبعث على الإلهام. تعد مبانى المتاحف من أهم المعالم الحضارية، والتى ترمز إلى مدى التقدم العلمى والتكنولوجى الذى توصلت إليه المجتمع، ذلك بالإضافة إلى أن تصميمها المعمارى يعكس مدى التطورالذى طرأ على أساليب التصميم المعمارى وكذلك أساليب التنفيذ. من بين تلك المتاحف والتى تأثر تصميمها بإستخدام تكنولوجيا الحاسب الآلى كان متحف جوجنهايم بلباو لفرانك جيرى، والذى أستخدم برنامج CATIA لعمل مجسم ثلاثى الأبعاد للمتحف، عن طريق عمل إفراد كامل لجميع الشرائح المنحنية المكونة لجسم المتحف.

حتى وقت قريب، كان التحدى الأساسى الذى يواجه المصمم خلال عملية تصميم المتحف هو الوصول لتصميم خارجى متميز، يطابق أفضل الحلول الوظيفية للمتحف، والذى يعكس فكرته التصميمة، وكذلك رسالة المتحف الثقافية. ينتج من ذلك مجموعة من الفراغات، والتى يتم من خلالها عرض محتويات المتحف بإسلوب فنى، بغرض إكساب زوار المتحف مجموعة من الخبرات، غير مكترثاً بطريقة توزيع المعروضات، والتى كانت توضع ضمن مهام القائمين على إدارة المتحف. فى الوقت الحاضر أصبحت مهمة توزيع المعروضات تندرج ضمن أعمال المصمم، ومن ثم أطلق عليه أسم مصمم المتحف أو Museographer. تعد قاعات العرض المتحفى أحد أهم الفراغات العامة داخل المتحف، وذلك لما تعرضه من قدر كبير من المعلومات للزوار، والتى تقدر على أساسها قيمة آى متحف. وللوصول لأفضل الحلول التصميمية للمتحف؛ فإنه على المصمم

أن يقوم بدراسة العلاقات الوظيفية بين أقسام المتحف و فراغاته المختلفة (عامة – إدارية – خدمية)، ذلك بالإضافة إلى دراسة حركة الزوار بين الفراغات المختلفة بشكل جيد فى جميع مراحل التصميم.

تهدف هذة الدراسة إلى إلقاء الضوء على العلاقة بين تصميم قاعات العرض المتحفى، وطرق توزيع المعروضات، وتأثير ذلك على حركة الزوار وكيفية تفاعلهم مع الفراغات المتحفية من خلال إستخدام منهجية التصميم بإستخدام الخوارزمات للوصول لمجموعة من الحلول المتطورة لتصميم قاعات العرض، والتى تم توضيحها من خلال تطبيق عملى، كجزء من دراسة تأثير إستخدام الخوارزمات فى التصميم المعمارى لمبانى المتاحف.

- **المشكلة البحثية**

"توثيق العلاقة بين إستخدام اساليب التصميم الخوارزمية، والتصميم المعمارى لمبانى المتاحف، وتأثير ذلك على تصميم قاعات العرض المتحفى "

- **أهداف البحث**

الهدف الأساسى:-

إلقاء الضوء على التأثير الناتج عن تطبيق منهجية وأدوات التصميم بالخوارزمات على التصميم المعمارى لمبانى المتاحف، وخاصة تصميم قاعات العرض.

أهداف ثانوية:-

- تغير الفكر الثقافى، وتأثيره على فكر المتاحف.
- تعدد أنواع المتاحف، وعلاقتها بأنواع المعروضات.
- رسالة المتحف الثقافية، والتى لها أثر كبير على طريقة توزيع المعروضات ، وكذلك حركة الزوار.
- أساليب التصميم بإستخدام الحاسب الآلى، وتأثيره على العمارة المعاصرة.

- **المنهجية البحثية**

يناقش البحث التصميم المعمارى لمبانى المتاحف بإستخدام تطبيقات الحاسب الآلى فى العمارة، وخاصة الخوارزمات، ولتحقيق أهداف الدراسة تم استخدام منهجية يمكن تفصيلها فى الخطوات التاليه:

١. **مرحلة جمع البيانات.**

بإستخدام الدراسة التحليلية والنظرية لعملية التصميم المعمارى لمبانى المتاحف، وذلك من خلال دراسة فراغات المتحف وأنواع الحركة داخلها، هذا بالإضافة إلى دراسة التأثير المتبادل بين طرق التصميم المعاصرة والمعتمدة على الخوارزمات والتصميم المعمارى.

٢. **مرحلة تحليل البيانات.**

بإستخدام الإستدلال الإستقرائى، للوصول لمنهجية توزيع المعروضات داخل قاعات العرض بإستخدام الخوارزمات، والتى تحقق رسالة المتحف الثقافية، موثقاً بمثال تطبيقى للمنهجية المقترحة للتصميم.

٣. **مرحلة إستخلاص النتائج.**

نستخلص من تلك الدراسة مجموعة من النتائج تتضمن كيفية إستخدام الخوارزمات فى تصميم فراغات المتحف وخاصة قاعات العرض. بالنسبة للتوصيات، فإنها تركز على عملية تصميم المتحف والتى تمكن المصمم من الوصول لأفضل الحلول والتى تحقق رسالة المتحف الثقافية.

- **هيكل البحث.**

يتكون البحث من خمسة فصول هى كالآتى:

* **الفصل الأول - مقدمة عن مبانى المتاحف.**

يتضمن هذا الفصل شرح مفصل للتغييرات الثقافية والإجتماعية من فترة ما قبل الميلاد وحتى القرن العشرين، والتى كان لها أثر كبير فى نشأة وتطور فكر المتاحف. ذلك بالإضافة إلى عرض لأهم أنواع المتاحف، وكذلك إلقاء الضوء على دور المتاحف فى المجتمع، واللذان يشكلان معاً دور رسالة المتحف الثقافية.

* **الفصل الثانى - تصميم قاعات العرض المتحفى.**

يتضمن هذا الفصل شرح تفصيلى للعلاقة بين العناصر الأساسية التى تشكل الخبرة المكتسبة لدى زوار المتحف، وعلاقتها بتصميم مبنى المتحف بوجه عام، وبالأخص تصميم قاعات العرض. ذلك إلى جانب تأثير حركة الزوار على طريقة توزيع المعروضات.

* **الفصل الثالث - التصميم بإستخدام الخوارزمات.**

يعرض هذا الفصل أساليب التصميم الرقمى المستخدمة فى التصميم المعمارى وأهمها الخوارزمات. ذلك بالإضافة إلى عرض تفصيلى لتاريخ الخوارزمات وطرق التعبير عنها وكيفية إدراجها فى التصميم المعمارى، وأنواع الخوارزمات المستخدمة فى التصميم، مدعمة بمجموعة أمثه لعدة مبانى تم إستخدام تطبيقات الخوارزمات فى تصميمها.

* **الفصل الرابع - التصميم المعمارى للمتاحف بإستخدام الخوارزمات.**

يناقش هذا الفصل كيفية إدراج الخوارزمات فى التصميم المعمارى لمبانى المتاحف، من خلال مجموعة من الخطوات الرقمية، وملحقاً بذلك عرض لثلاث متاحف مختلفة تم إستخدام الخوارزمات فى تصميمها.

* **الفصل الخامس – تصميم قاعات العرض بإستخدام الخوارزمات.**

يعرض هذا الفصل إحدى منهجيات التصميم العملية بإستخدام الخوارزمات لقاعات العرض المتحفى ، والتى تم التحقق منها من خلال التطبيق العملى.

* **النتائج والتوصيات.**

يعرض هذا الجزء ملخصاً للبحث وكذلك أهم النتائج التى توصل لها البحث والتى تمكن للمصمم من تحقيق رسالة المتحف الثقافية، من خلال منهجية جديدة لتصميم قاعات العرض، هذا إلى جانب بعض المقترحات الإضافية للحصول على نتائج أفضل.