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„THE ROLE AND IMPACT OF TECHNOLOGY ON ARCHITECTURE FROM INDUSTRIAL TO NANOREVOLUTION"

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Dedicated to the remembrance of my dear uncle; Ergun GÜR

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ABSTRACT

The development of civilisation is inseparably bonded to the technology that has the tendency to transform everything and architecture is affected by the thrust of technology through history. The history of architecture is the history of technology that encompasses the whole evolution of man. In this study the role and impact of technology on architecture is discussed briefly from industrial revolution to nanorevolution. However like in any discipline, the discipline of architecture is far too involved and complex to ascribe major developments to one cause only.

Some technological advances have the potential to change conceptually the design practice with new functional solutions and aesthetical expressions. The technological development of architecture has been dependent on discoveries surrounding the best capacities of each material. Evolutionary process is occurred from simple construction methods, based on local resources to an increasing use of commercially produced building components.

Architecture presents itself with different materials that made it. The Industrial Revolution's central material fact, industrialized iron brought new possibilities, and drastically changed most of the traditional modes of design and construction. New structure systems and building forms appeared without precedent in the previous history. Tall building was the most remarkable new building type to emerge in the 19^{th} century. It has entirely changed the scale, appearance, and concept of cities with its great visual impact. With advanced technologies the skylines of the cities dominated by tall buildings all over the world in 20^{th} century. In the 21st century it can be expected that more and more innovative tall buildings will be built, utilizing the cutting-edge techniques. In this study tall buildings are selected as a case building type because they require most advanced contemporary technologies in consequence of their scale and complex nature. The purpose is to describe in a condensed form the development of tall buildings over the full period of time in which that evolution took place, by investigating the role and impact of technological advancements. Particularly the improvements which have directly impacted the form, expression and general design practice are discussed.

The real need to stop harming the natural systems begins to shift architectural practice with a popular environmental movement which began after the oil crisis of 1973. In a world with growing concerns about global energy use and carbon emissions, energy efficient and sustainable building design becomes a necessity. For designing and building a sustainable future the impact of the smart materials are significant. To produce energy from renewable sources, smart materials offer beneficiary solutions. The true material selection plays a key role for the sustainability. During the 20^{th} century it was possible to select high performance smart material to meet a specifically defined need.

The study concludes with a review of the way in which nanotechnology will become a driver of change in the future by the understanding of materials and controlling their structure at the nanoscale. This technology can be seen as the Industrial Revolution of the 21st century because of its great potential to create a range of materials with novel characteristics, functions and applications. It has the potential to change the rules of architectural design practice and, civil, electrical and mechanical engineering, as well as other professions to break away from their traditional design parameters.

KURZFASSUNG

Die Entwicklung der Zivilisation ist untrennbar mit der Technologie verbunden, die die Tendenz hat, alles zu transformieren. Architektur ist durch den Vorstoß der Technik, durch die Geschichte geprägt. Die Geschichte der Architektur ist die Geschichte der Technologie, die die gesamte Evolution des Menschen umfasst. In dieser Arbeit werden die Rolle und Auswirkungen von Technologie auf die Architektur kurz diskutiert, von Industrieller Revolution zu Nanorevolution. Doch wie jede Disziplin, so ist auch die Disziplin der Architektur viel zu komplex und involviert, um die wichtigsten Entwicklungen nur auf eine Ursache zurückzuführen.

Einige technologische Fortschritte haben das Potenzial, die Konzeptionen der Design-Praxis mit den neuen funktionalen Lösungen und ästhetischen Ausdrucksformen zu ändern. Die technologische Entwicklung der Architektur wurde von Entdeckungen rund um die besten Kapazitäten der einzelnen Materialien ausgelöst. Evolutionäre Prozesse sind aus einfachen Konstruktionsmethoden entstanden, die auf lokalen Ressourcen basieren, bis hin zu einer zunehmenden Verwendung von handelsüblichen Bauteilen. Neue Strukturen und Aufbau von Formen erschienen ohne Präzedenzfall in der früheren Geschichte.

Architektur definiert sich durch die verschiedensten Materialen, die sie entstehen ließen. Industrialisiertes Eisen, das zentrale und wesentliche Material der industriellen Revolution, brachte neue Möglichkeiten und veränderte drastisch die meisten traditionellen Formen der Planung und Bauweise. Neue Strukturen und Aufbau von Formen erschienen ohne Präzedenzfall in der früheren Geschichte. Hochhäuser wurden der bemerkenswerteste neue Gebäudetyp im 19. Jahrhundert. Sie haben den ganzen Maßstab, das Aussehen und das Konzept der Städte mit ihrer großen visuellen Wirkung verändert. Im 20. Jahrhundert wurde die Silhouette der Städte von Hochhäusern auf der ganzen Welt mit fortschrittlichen Technologien dominiert. Im 21. Jahrhundert ist zu erwarten, dass mehr und mehr innovative Hochhäuser gebaut werden, unter Verwendung modernster Techniken. In dieser Arbeit ist das Hochhaus als Beispiel eines Gebäudetyps ausgewählt, denn es erfordert modernste zeitgenössische Technologien in Folge seines Maßstabes und seiner Komplexität. Der Zweck ist es, in komprimierter Form die Entwicklung von Hochhäusern über den gesamten Zeitraum, in dem die Entwicklung stattgefunden hat, zu beschreiben - durch die Untersuchung der Rolle und des Einflusses des technologischen Fortschritts. Vor allem die Neuerungen, die direkt die Form, den Ausdruck und die allgemeine Design-Praxis beeinflussten. Umweltbewusstes Planen und Bauen begann die architektonische Praxis nach der Ölkrise von 1973 zu verändern. In einer Welt mit wachsender Besorgnis über globalen Energieverbrauch und Kohlenstoff-Emissionen wird es zu einer Notwendigkeit, energieeffiziente und nachhaltige Bauplanung zu erschaffen. Für die Gestaltung und den Aufbau einer nachhaltigen Zukunft sind die Auswirkungen der intelligenten Materialien signifikant. Für die Herstellung von Energie aus erneuerbaren Quellen bieten intelligente Materialien leistungsberechtigte Lösungen. Die wahre Materialauswahl spielt eine entscheidende Rolle für die Nachhaltigkeit.

Die Studie schließt mit einer Übersicht, dass die Nanotechnologie zu einem Motor des Wandels in der Zukunft sein wird, durch das Verständnis der Materialien und die Kontrolle ihrer Struktur auf der Nanoebene. Diese Technologie kann als die industrielle Revolution des 21. Jahrhunderts angesehen werden - wegen ihres großen Potenzials, der Schaffung einer Reihe von Materialien mit neuartigen Eigenschaften, Funktionen und Anwendungen. Es ändern sich die Regeln der architektonischen Gestaltung und Praxis, Zivil-, Elektro-und Maschinenbau, außerdem gehen andere Disziplinen weg von ihren traditionellen Design-Parametern.

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PART 1: ARCHITECTURE AND TECHNOLOGY

1.1. The Relationship between Architecture and Technology

Technology is a crucial part of civilisation and the inevitable element that architecture deals with. The development of civilisation is inseparably bonded to the technology and the history of architecture is the history of technology that encompasses the whole evolution of man. It reveals an interaction between the inducements and opportunities of technological innovation on one side and the socio cultural conditions of the society on the other [1.1].

The impacts of technology on the architecture have been largely evolutionary and the acquirement of techniques is a cumulative matter. Over a long period of time the history of technology inevitably highlights the moments of innovation which show this cumulative quality, from comparatively primitive to more sophisticated techniques. This development has occurred and is still going on [1.1-2].

'Technology' in the encyclopedia of Britannica defined as *the systematic study of techniques for making and doing things*. The term itself, a combination of the Greek *techne,* "art, craft," with *logos,* "word, speech," meant in Greece a discourse on the arts, both fine and applied. It was used to mean a discussion of the applied arts only, when it first appeared in English in the 17th century; then these "arts" came to be the object of the designation. Technology included a range of means, processes, and ideas in addition to tools and machines, by the early 20th century. By the second half of the century, the term was explained as "the means or activity by which man seeks to change or manipulate his environment."[1.1].

Technology can be defined as the systematic study of techniques for making and doing things with the application of science to production and this also includes architecture. It includes different materials, techniques, processes, tools, the buildings themselves during the course of production and their use [1.3]. Technology has the tendency to transform everything and architecture is affected by the thrust of technology through history. The oldest architecture began with a great change in society through the transition from hunter-gathering to agriculture and the

Fig. 1.1: Pillar with relief

Fig. 1.2: A computer reconstruction

Fig. 1.3: T shape pillars

emergence of complex societies with permanent settlement. However, at Göbekli Tepe (Navel Mountain) with its unexpected amount of Megalithic architecture proves that hunter- gatherers were capable of complex art and organised religion, something no-one imagined before. Remnants are considered to be one of the first examples of architectural structure. It dates from 10,000BC, before pottery and the wheel that's 12,000 years old [1.4].

At Göbekli Tepe, which is an early Neolithic site in south-eastern Turkey, stand megalithic limestone pillars. So far, 40-odd standing stones (two to four metres high) have been dug out. They are T-shaped and arranged in enclosed circles, which cover several hundred square metres. Many of them have reliefs depicting various animals such as lions, gazelle, foxes, snakes, wild cattle, wild ass and wild boars. These pillars are quite large and heavy, with the largest pillar weighing over 50 tons. Excavator Dr. Klaus Schmidt[1] considers Göbekli Tepe as a center for a complicated dead cult and interprets, "*This was monumental architecture, 6000 years before the pyramids*." It is quite dominating and visible from over 20 kilometres away. The archaeological team working under Schmidt try to understand the pre-pottery society that existed there. Their architectural techniques, the use of T-shaped pillars, showed an advanced knowledge of how to build strong, load-bearing structures. The pillars suggest that early Neolithic workers knew how to use poles, boards and pulleys to handle huge stones[2] [1.5].

Historically construction was based on practical experience, learning by trial and error. The design of most building elements was based on experience; rules were empirical rather than theoretical. The possibilities of construction technique changed very little from century to century up until the mid-eighteenth century. The

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[1] "The geometrical forms and small animal reliefs are surely more than just ornamentations. Humans somewhat wanted to communicate with future humans here " he says in a February 14, 2006 Berliner Morgenpost article.

[2] Although the buildings at Göbekli Tepe seem to have required large groups of people to build, no signs of permanent settlement like fires, ovens, or domestication have been found at the site. This would suggest that it was an important place where different groups of hunter-gatherers in the region would gather, possibly to participate in ritual activities and build the structures together (Schmidt 1998).

traditional mode of design and construction techniques until this time is not so complex because of the limited range of methods available for the construction and the relative stability of structural forms [1.6].

Architectural design at all times had to rely on the technology of the time by adapting existing technologies to locally available materials. Progressively, more and more has come to be grounded on science. The advances in technology would not have been possible without the growth of science. Science is used as a testing ground for reliable predictions and technology allowed for confidence in the design of accurate building structures. It has been all along a permanent goal, to state the scientific nature of the discipline of architecture. The distinction between the "science" and "art" of architecture has a long tradition in architectural theory. Yet there is no common understanding as to the exact relationship between them, their proper balance, or even what the art and science consist of [1.7].

During the fifteenth century Renaissance theorists, who were inspired by Vitruvius, tried to build a scientific basis for architecture. The following centuries saw the creation of new scientific studies. This progressive movement continued and advanced mathematical, scientific and engineering studies developed in the early 1700s with the Industrial Revolution[3] [1.2].

Knowledge progressed rapidly in the newly created branches of science and the results of this technological and scientific progress affected the design practice [1.8]. By the application of science, mathematical methods were developed for the needs of building and engineering. The rapid development and evolution of

[3] The Industrial Revolution occurred first in Britain, and its effects spread gradually to continental Europe and North America. The term is imprecise because it has no clearly defined beginning or end. The events of the Industrial Revolution had been well prepared in a mounting tempo of industrial, commercial, and technological activity from about AD 1000 and led into a continuing acceleration of the processes of industrialization that is still proceeding in our own time. It is used to describe an extraordinary quickening in the rate of growth and change, and more particularly, to describe the first 150 years of this period of time, as it will be convenient to pursue the developments of the present century separately [1.1].

structural and mechanical theory in the seventeenth and eighteenth centuries altered the design practice of the time. Experiments that investigate the mechanical properties of materials provided an alternative approach for selecting materials and for sizing and shaping building elements [1.8]. Parallel to the progress in materials sciences, the technology of construction and manufacturing of building materials have also evolved tremendously [1.3].

It is the cumulative character of technology that provides the transmission of technological innovations. Although the technology depends characteristically on principles of science; the close connection occurred during the 19th century and technology gradually became based on science [1.1].

1.2. The Impact of Materials-Related Innovations

Overall visual characteristics of buildings were affected by the materials-related innovations. The knowledge about building materials and the technology for making buildings generated even the basic nature of classical architectural orders and later refinements by Palladio and others. The proportions of the Palladian order are not unrelated to knowledge at the time about how to carry brick structurally, how to make glass, and how to manufacture frames capable of carrying glass [1.8-9]. Architecture presents itself with different materials that made it. It is the combination of art and technique of designing, shaping, and decorating the materials of which a building is composed [1.2-10].

The climate and the local availability of materials are the chief external determinants. The materials influenced the design and construction of buildings as climatic modifiers. In particular, the climate has influenced the general shapes, shapes of openings and plan organizations of building complexes; designers have tried to mitigate various environmental conditions. The form and construction of many early buildings were responsive to the prevailing climatic, technical and socioeconomic conditions. The arrangement of structural and enclosure elements in early buildings was also influenced strongly by the mechanical properties of the materials and the technologies for producing and assembling the materials [1.8].

The design of architecture relies on the materiality of the structure and system chosen to frame and clad the building. Beyond the other parameters, architecture derives much of its meaning from the treatment of its façade. Glazings and fenestration are the prominent elements of architectural form and expression [1.11]. Windows in buildings have progressed over time from small openings to meter-sized punched openings and finally to complete all-glass building skins. Various materials adopted by different societies to enclose different wall openings. The basic technique for making the modern window was in place by around 750 BC when it was found that glass could be blown using a pipe. Blowing glass could be made very thin. This remarkable material, hard, transparent, and capable of being formed could keep the weather out of buildings and also admit light and view. It was the Romans who began to use glass for architectural purposes, with the discovery of clear glass (through the introduction of manganese oxide) in Alexandria around AD 100. Blown glass had dominated the industry for centuries, although it was thin and weak [1.12].

Architecture should respond to technological and environmental concerns. With the growth of science and technology broad material benefits were achieved. Evolutionary process is occurred from simple construction methods, based on local resources to an increasing use of commercially produced building components. The technological development of architecture has been dependent on discoveries surrounding the best capacities of each material [1.2]. Materials-related innovations were not the only cause of significant changes in architecture. Like in any discipline, the discipline of architecture is far too involved and complex to ascribe major developments to one cause only. However, changes have been possible because of, and were encouraged by, developments in the field of materials. With these developments designers began to think differently to meet building needs [1.8].

From the Middle Ages to 1750 construction was carried out mostly with the methods of High Middle Ages and the Renaissance [1.13]. The practice of building in stone and brick became general and timber continued to remain as an important building material [1.1]. The load bearing wall of brick and stone limited the width opening. This limitation was exceptionally overcome, such as in the developments culminating in the Gothic cathedral. In the Romanesque and Gothic periods, particularly, the wall became a surface activated both visually and structurally by a series of arched and vaulted openings, illuminated by panels of stained glass. The Gothic cathedral was the first architecture to break up the wall in favour of the window. The purpose was, rather than transparency, to give light to the interiors of huge volumes, and to use the richness of colour which glass had always been able to deliver [1.12-14-15]. Glass was beginning to become an important feature of buildings of all sorts and cast iron was beginning to be used in buildings for decorative purposes [1.1].

The methods for the mass production are developed in the iron[4] industry at 18th century; cast and wrought iron were being produced in England on a commercial scale. The Industrial Revolution's central material fact, industrialized iron brought new utilities such as the railway[5] [1.16]. Industrial development and the needs of the railways served as a backdrop to the development of the science of the strength of materials [1.3]. Thus durable materials with good tensile strength became available in large quantities for use in building. To use iron as a construction material (first cast iron, then various types of steel) was possible between the 18th and 19th centuries[6]. At the end of the 18th century the material was increasingly used in the construction of bridges and buildings.

Only between 1800 and 1850 a new, common system for processing materials was occurred and then the idea of the machine appeared. The first clear realization

4 Production Iron during the late eighteenth century constituted the first truly modern structural material. The advent of Iron construction in France and England coincided with the growing separation between the definition of Architect versus Engineer.[1.2]

5 In the 1830s, railway construction was expanding. [1.17]

6 Important contributions to iron architecture were done by an architecture theorist Emmanuel Viollet-le-Duc. He saw in this product of modern industry the technological means to create structures that it had previously not been possible to build with traditional means. He recognized the rational construction method of Gothic architecture as an ideal model for iron framework designs. In the second volume of his "Entretiens sur l'architecture", published in 1872, he strongly advocated the freely supported iron framework in combination with brick walls [1.21]. He believed that all good architecture was based on a rational system of structure and organization reflecting the social conditions of the time and the building technology available [1.9].

occurred in connection with the great economic events of the nineteenth century [1.18].

During the latter half of the nineteenth century International Industrial Exhibitions held in England and France. These exhibitions were an opportunity for experimentation and exploitation of iron and steel and an encouragement to challenge traditional methods and materials. Because of its marked strength capabilities and ability for fast erection and disassembly, iron or steel were used for the primary structure of significant architectural icons [1.2].

Fig. 1.4: Crystal Palace by Joseph Paxton

Joseph Paxton developed a metal-frame structure of cast and wrought iron for the Crystal Palace (a greenhouse) for the first International Industrial Exhibition of 1851 in London. The frame was clad with glass (used over 300,000 sheets of glass), supplemented by a complex system of braces, flanges and torsion rods [1.19]. Crystal Palace is considered as an important stage in the development of iron framing[7]. It was influential for its practicality because of the application of the principles of iron construction, industrialized assembly[8] and glass technology. Considerable progress was made in all areas of glass production in the 19th century. After 150 years of development, the customary 'crown' process manufactured only limited sizes of glass pane, which led to its decline in the 1830s. It had provided panes of 0.75 x 0.5 m, but the majority of panes were of smaller dimensions. This can be seen in the design of the eighteenth and nineteenth century window with its divisions of mullion and transom. In the 1830s the new improved 'Cylinder' process manufactured, providing glass of more uniform thickness in sizes up to 1.0 x 1.3 m [1.20]. Glass was now available to seal the larger openings in the facades of the new skeletal constructions. This process, which was an early form of mass production, permitted the rapid construction of the Crystal Palace. Although they were temporary structures, the Palm House at Kew Gardens (1845),

[7] According to the architectural historian Folke T. Kihlstedt, Crystal Palace is as influential a building as the Pantheon, the Hagia Sophia. [1.22]

[8] The work Paxton is testimony to the successful transfer of ideology from classical arrangement to prefabricated modular cast iron design. Such highly organized prefabricated works would not have been possible using traditional classical materials and methods.[1.2]

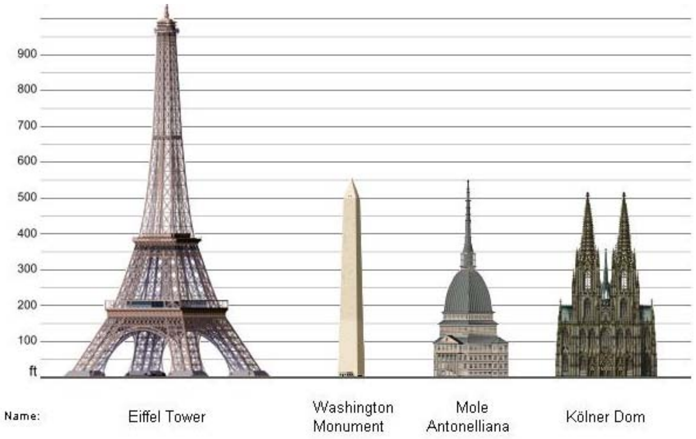

Fig. 1.5: Eiffel Tower

Fig. 1.6: Brooklyn Bridge

and the Crystal Palace were the first examples of mass-produced, pre-fabricated buildings with thin enclosures separate from the structure.
The change from cast and wrought iron to steel (around 1880-1900) allowed the use of higher permissible stresses and larger rolled sections [1.23]. Henry Bessemer's[9] invention in 1856 drastically reduced the price of steel and made it competitive with cast iron and wrought iron. Since steel combined ductility with high strength, it soon replaced both cast iron and wrought iron for most structural applications [1.24]. The new structural building material was provided by the growing steel industry.

Another important exhibition held in France for the Paris Exposition of 1889 provided a platform for structural experimentation with iron and steel. The Galerie des Machines by Victor Contamin and the Eiffel Tower which were constructed for this exhibition considered as impressive with their structural steel design.[1.2] The triumph of the machine was marked by this Exposition, a new attitude developed among theorists and society in general [1.18].

Eiffel Tower symbolizes the progress in construction technology with its originally 300 meters high, that was taller than any previous man-made structure [1.17]. Eiffel tower, the first skyscrapers of Chicago (1880-1900) and Roebling's Brooklyn Bridge (1883 in New York) are convincing landmarks for the expansion of structure concepts to its limits, and they were considered as climaxes and promises. They were reliant on the material and structural characteristics of iron or steel to form the basis for their existence [1.2]. The primary motivation of each was to span unprecedented[10] distances with new structural building material. They symbolize an artistic and rationalistic vision of the technological world.

[9] In 1856 Henry Bessemer invented the process named after him for blowing air through the fluid pig iron, instead of reducing the carbon content by the traditional laborious puddling process. His invention drastically reduced the price of steel and made it competitive with cast iron and wrought iron. Steel had until that time been a very expensive material, because it could only be made by reducing the carbon content of cast iron, or by increasing the carbon content of wrought iron. [1.24]
[10] Throughout the history pushing the limits by making technology and materials work as hard as possible was a general aspiration

With the application of the methods of theoretical and experimental science to the design of structures, the extreme demands of the Industrial Revolution drastically changed most of the traditional modes of design and construction. The new industrialized materials served the building process more efficiently in terms of material cost and construction ease and they would come to replace previous methods and materials. Steel, as a structural material, became an icon for technology and modernity in the 20th century [1.9].

During this age of invention and industrialization, not only mass-production methods and new approaches to construction developed, but also new structure systems and building forms appeared without precedent in the previous history. With the advent of new materials and advanced technologies, the new structures became the signs of progress. Multi storey steel framing, the invention of the skyscraper, and curtain wall construction had a great influence on architectural design and theory.

The most important factors in skyscraper development during these early years were the invention of the iron frame. Masonry bearing wall construction had not enough strength and flexibility for a skyscraper and conventional methods of building in brick and masonry had reached the limits of feasibility [1.1]. Iron frame (a frame of ferrous metals of various kinds) displaced solid, load-bearing walls. It is seen as a symbol of the Industrial Revolution that causes urbanization and rapid population growth. Manufactured iron in pieces of prismatic wholes assembled to form the structure of buildings and the structure of a building became a skeleton that partially free of its walls. This conceptual shift allowed thinking of the structure of a building as a skeleton partially free of its walls and it made architectural space independent from construction method in a way unknown until that time [1.13]. The using of rolled steel and reinforced concrete were supplemented by the 'curtain wall' which was hung from the exterior frame at each floor. Having no structural purpose, it could be made of thinly cut stone, glass and metal or any other material [1.25]. The post and lintel construction, made available larger window openings, for all types of building. Glass was the inevitable material to seal the new, hard won, openings [1.14]. Curtain wall systems freed the material choice from utilitarian functions so that the façade could become a purely formal element.

The socio-economic changes, combined with the positive properties of steel-skeleton structures resulted in space-saving structural areas and transformed Chicago and New York into skyscraper cities [1.19]. It is envisaged by few people that the production and use of materials such as cast iron and steel would have so dramatic impact on design practice. But these products were developed step by step and then used in built environment.

The role of materials changed dramatically with the advent of the Industrial Revolution. Architects began to be confronted with engineered materials. Materials transitioned from their pre-modern role of being subordinate to architectural needs into a means to expand functional performance and open up new formal responses. Glass and the steel skeleton came together as key elements in the modern architectural movement. The industrialization of glass-making enabled the 'international style' in which a transparent[11] architecture could be sited in any climate and in any context.

The predominant type of structural system for steel or concrete tall buildings began to change by the early 1970s. Through advancements Computer Aided Design/Computer Aided Manufacturing technologies, engineering materials efficiently and easily employed. By the advent of high-speed computers better understanding of the mechanics of material and member behaviour is achieved. The rational structural analyses were possible in three dimensional simulations. Thus, tall building structural systems have become much lighter than earlier ones with different solutions.

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[11] The development of framed building liberated window area [1.8] Glass was the inevitable material to seal the new, hard won, openings. In 1914, the German visionary writer Paul Scheerbart described his dream of a world revivified by glass architecture: *If we want our culture to rise to a high level, we are obliged for better or for worse, to change our architecture. ... We can only do that by introducing glass architecture, which lets in the light of the sun, the moon, and the stars, not merely through a few windows, but through every possible wall, which will be made entirely of glass [1.14].*

The evolutionary change in architectural profession is being driven by the invention of new materials or new industrial tools. For the first time since the rise of modernism the real need to stop harming the natural systems, begins to shift architectural practice. A popular environmental movement began after the oil crisis of 1973 which had a direct effect on architecture. It has been realized that overall energy use in buildings could be reduced with better design and improved technology. New approaches to the design of tall buildings can have a major impact on sustainability. Improvements in construction techniques and advances in building services have contributed to the potential to make greener high-rise buildings. During the 20th century it was possible to select of a high performance smart material to meet a specifically defined need. Smart materials allow even a further specificity – their properties are productive and changeable.

Scientific revolutions have transformed the methods and meaning of design and architecture through the history. It has undergone great changes over its history. Currently, construction industry is able to use several technologies such as information technology, modern science, e.g. nanotechnology, biotechnology, robotics. Among them nanotechnology has the potential to be the Industrial Revolution of the 21st century. It will be as influential in the 21st century as digital revolution was in the 20th century. Nanotechnology offers the opportunity to design and build in new ways. Research on nanotechnology is key factor for the development of high-tech materials. The properties of the materials can be deliberately improved by introducing characteristic structures on the nanometer scale and it is also possible to create new materials with new manufacturing methods. Nano-enhanced products can be made in very precise and controlled ways, which are smaller, cleaner, cheaper, faster and smarter. With these completely new materials and components more durable, efficient, cost-effective and superior buildings can be realized. It has the potential to provide the basis for a sustainable development of industry.

Modern tall buildings are becoming taller, more complex and more sustainable with the advances in structural design and high strength materials. There is a need for construction to increase its capacity to develop the capabilities to benefit from nanotechnology. This new wave of change will create a continuing series of new breakthroughs with new materials, devices and systems.

Over the past the impacts of technology on architecture have been largely evolutionary. In the future, however, there is a high potential for significant developments which will impact the discipline of architecture. These developments will capitalize on advances already apparent in other disciplines. It is significant understanding the fundamental principles of architecture-related disciplines.

1.3. Technology and Aesthetic

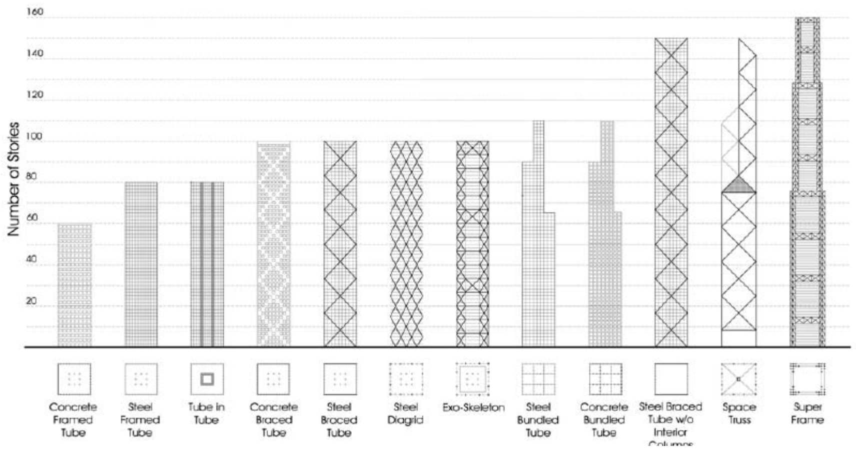
Architecture is the 'art' and 'science' of designing building and the distinction between these two notions in architecture has a long tradition in architectural theory. But there is no general understanding as to the exact relationship between them. Function, structure, and form are bounded in architecture and it should be a balance among these three elements. At the beginning of the first century Vitruvius suggested in his work *De architectura libri decem* that good buildings satisfy three core principles: in latin *"firmitas"*, *"utilitas"* and *"venustas"*. Morgan translates this as "durability, convenience and beauty" [1.14]. First, a building must have durability; it must be well-constructed using quality materials. The second quality a building must be functional, and finally the work must possess a sense of aesthetics, beauty or expression that allows it to transcend the realm of the ordinary. While durability and convenience are tangible values that can be judged more objectively, beauty is open to the individual subjectivity. [1.26]

G. Santayana's general statement defines:
"*Beauty is pleasure regarded as the quality of a thing. Beauty is a value, that is, it is not a perception of a matter of fact or of a relation: it is an emotion*." [1.27]

In architecture well synthesized technical and aesthetic feature provide the beauty. The discipline of architecture encompasses the art and science at the same because of its intrinsic nature. Thus, the aesthetic qualities of architecture can't be simply defined by formulas, as in the sciences. By the help of applied science and technological advancements new materials, which have new mechanical thermal and chemical properties, are provided. The transformation from these physical elements into aesthetical satisfying objects is achieved by the architect's sense of form, order and harmony [1.10]. Aesthetics is an emotional and, therefore, not an entirely scientifically objective matter.

Sigfried Giedion describes the influence of Eiffel's earlier structure, the Galerie des Machines of the Paris International Exhibition of 1867:
"*In all sorts of ways--by the extensive use of new materials, by the employment of new devices like the elevator, by the provision of walks along the transparent glass surfaces of the 'promenoirs'--the public was introduced not only to the new technical achievements but also to completely new aesthetic values*."[1.27]

Some technological advances have the potential to change conceptually the design practice with new functional solutions and aesthetical expressions. In architecture aesthetic expression is sought continuously through every new emerged technology with its new materials with different performances. But the impacts of technology on architecture have been largely evolutionary. The developments which are significant, marking the beginning of a new development or era, is not so often. When it is occurred it is complicated to find the appropriate aesthetic solutions for these unprecedented breakthroughs.



PART 2. THE EVOLUTION OF THE TALL BUILDINGS

Fig. 2.1: Historically Tallest Buildings

PART 2. THE EVOLUTION OF THE TALL BUILDINGS

2.1. Introduction

The tall building is the most remarkable new building type to emerge in the 19th century. It has entirely changed the scale, appearance, and concept of cities with its great visual impact and became the symbol of those cities. Traditionally the function of tall buildings has been as commercial office buildings. Other usages, such as residential, mixed-use, and hotel tower developments have since rapidly increased. A tall building can be defined by the property of 'tallness', which is substantially taller than its neighbours and significantly change the skyline. There are various factors that played prominent role in the evolution of tall buildings; such as technological, economical, sociological, aesthetical considerations and zoning laws, and building codes.

The emergence of skyscraper was a response to the growing population rate in the urban areas. This building type was an ideal solution for economically optimized land use at that time. Demographic outcomes show an enormous population growth and increased density in urban areas also in the future. The world's population is expected to reach 9,1 billion by the year 2050 according to Official UN Estimates. A report by the UN Population Fund says more than half of the world's population will live in cities by 2008 and a number expected to swell to almost 5 billion by 2030. The global population growth and the increasing rate of urbanization make tall buildings inevitable solutions especially in high-density urban cores. In the 21st century it can be expected that more and more innovative tall buildings will be built, utilizing the cutting-edge techniques to meet the needs. That is one of the main reasons why tall buildings are selected as a case building.

Architecturally, structurally and aesthetically, it is a complex task to design tall buildings. This complexity comes from the building's scale and the interrelations of large numbers of components. Historically, the development of the tall building has been dependent mostly on technological advancements. A study of the evolution of the tall buildings that does not highlight the significance of technology is incomplete. Various technological improvements have significantly impacted the tall buildings. Particularly the improvements which have directly impacted the form, expression and general design practice of tall buildings are discussed in this study. Historical developments of the tall buildings reveals an intrinsic link between the development of new technologies and new materials, the technological advancement of existing materials and advances in environmental control systems.

The historical overview of the tall buildings from their emergence to the recent design solutions is presented with examples. By the use of realized and projected examples my attempt is to demonstrate the role and impact of technology on architecture. These examples of tall buildings display not only the technical but also the aesthetic and environmental issues encompassed by the realm of modern technology.

The Pre-Conditions:

The technical evolution of the tall building in the second half of the nineteenth century was only made possible by the earlier independent development of its essential components. The advances in technology were made possible the rapid rise of building. These included the cage and skeleton construction, elevator, fireproof protection for columns and beams, isolated footings and caisson foundations [2.1-2].

Before the nineteenth century tall buildings were mostly masonry structures. But masonry construction was not efficient for multistory application because of the technological features of their structural systems, such as its thick massive walls and relatively low tensile strength. The last great bearing-wall brick structure of that era was the 16-story Monadnock Building [1889-91] by Daniel Burnham and John Wellborn Root in Chicago. The walls had to be more than 6 ft thick at the base and the solid brickwork occupies nearly one-fifth of the building area [2.1]. The desire of a new building type was considerable.

Besides the purely constructional problems, also the involvements of many other factors were needed for the development of tall building. The problem of vertical transportation of people as well as other building services such as electric lighting, steam heating systems[12], telecommunications, mechanical ventilation and sanitary facilities should be solved.

With the invention of passenger elevators by Elisha Graves Otis in 1854 the height of a building was no longer limited. His first safety passenger elevator was installed in the Haughwout Building in 1857 in New York and the first use of elevators in office buildings was in Equitable Life Assurance Building in New York in (1868-70), by George B. Post [2.3-1]. It rose to a height of 130 feet with five working stories. Post kept the exterior granite piers but used wrought iron beams in the interior, thus the cost of construction costs was reduced [2.4].

Within five years the appropriate economic conditions doubled the height of the New York skyscraper; Post's Western Union Building with the height of 230 feet, and Richard M. Hunt's Tribune to 260 feet. They relied on the same combination of masonry walls and partitions supporting wrought-iron beams [2.4]. This mass of masonry on this scale limited the usefulness of the floor, the deep reveals of the office windows impeded the admission of daylight, but at that time New York engineers and architects were slow to take advantage of the new techniques. Although their masonry structures, these buildings are considered as an early version of the skyscraper with required technical factors, except an all-frame construction and height [2.2].

The buildings that have been built between the years 1849 and 1870 had the essential components of a skyscraper but these elements were not assembled into a single structure. At that time heavy industry was experiencing a major boom and there was an enormous pressure on economic expansion, thus iron became the obvious choice. The most important factor in tall building development during these early years was the invention of the skeleton frame, which displaced solid, load-bearing walls. The great alteration in structure with the use of all skeleton iron

[12] Steam-operated power-driven fans for ventilation were available in the 1860s; air conditioners were introduced in the 1920s [2.1]

construction and the ability to provide lateral stability was a great breakthrough in the history of architecture [2.5].
Another important factor under these above mentioned technical preconditions for tall buildings was the requirement for fire resistance. After the Great Fire in Chicago between 8th and 10th October 1871 the need for a method of fire-resistant construction on a large scale was occurred, because the fire had melted exposed cast-iron members of the buildings into a completely fluid state. This experience led to new solutions such as the protection of metal skeleton. The iron beams and columns of the buildings were covered with heat resistive insulation with tiles[13] to prevent their failure. Improvements in fireproofing systems were an important prerequisite for the age of the skyscraper [2.1]. The utilization of these technical factors brought the revolution in form and construction and it became the basis of a modern architecture. The architects were concerned with the technical and aesthetic problem of creating a form appropriate to the needs[14] of the new industrial culture [2.6].
The first use of skeletal construction in New York was in the eleven-storey Tower building by Bradford Gilbert (1888-89). Although it was built four years later after the Home Insurance Building, the traditional and the advanced were combined in Tower building. Skeletal structure was used for the interior framing but for the façade traditional solid bearing masonry structure preferred. In the transitional period from traditional solutions to fully framed construction, this kind of composed/hybrid solutions practiced [2.4].

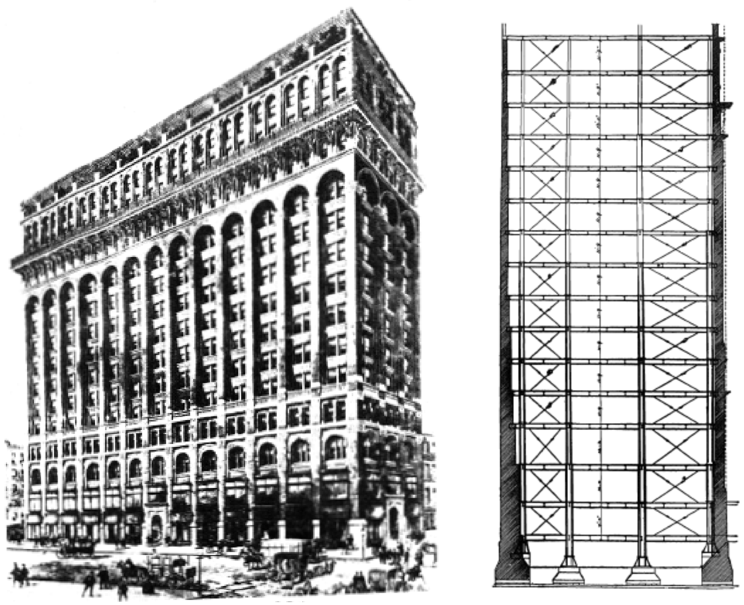


Fig.2.2: Havemeyer Building Cross section of Havemeyer Building

Another example of this composed solution was used by George B. Post in the fifteen-story Havemeyer Building (1891-92). The building was the combination of skeletal structure and masonry for the façade. For the most part the interior and wind loads were carried on an iron frame with double-diagonal bracing in the outer bays. The masonry walls carried not only their own weight but also a small portion

[13] After 1871, under pressure from fire insurance companies, a system coated with terra-cotta was developed in Chicago. This paved the way for giant iron framework constructions. [2.3]
[14] The buildings required a different design solution, the decorative French system is replaced by a more modest usage, for instance by replacing the mansardic roof by a flat one, better and more rental space at less cost was provided.[2.2]

of the peripheral floor loads. The wall thickness was reduced in steps up the height of the building as the vertical load and the overturning force of the wind progressively decrease. Masonry walls are rigid and heavy enough to resist the force of wind up to a certain height. Havemeyer Building closely approached fully framed construction [2.4]. Even after the usage of fully framed structures in tall buildings, façade systems of the early buildings did not fully express this technological innovation.

2.2. The Emergence of Tall Buildings

In late nineteenth-century, the skyline of central business districts in United States, first in Chicago and then in New York, began to change. At that time Chicago was one of the fastest growing cities in the world which situated strategically on the main transcontinental railway and water routes. In 1833, Chicago had just 150 inhabitants. In 1848, it was 20.000, and around 1870, 300.000 [2.2]. The city had a great demand for residential space and office buildings because of the growing complexity of modern industry. Concentrated administrative centres where large numbers of people could work were needed. It was inevitable to maximise the profit of land with taller buildings. The big office buildings with a new type of structure for the crowded commercial area became a necessity.

The architects and engineers who rebuilt Chicago after the Great Fire15 responded to the growing industrialization and population of the city by developing the the modern multi-storey building. They had to master new materials and offer different solutions to new problems. The forms of the past had little meaning in the face of the new conditions in those years. An aesthetic discipline that would encompass the expression of the new mechanized industry and the technology should also be provided. The exterior form should represent the new conditions of urban life in the great centers of trade and manufacture [2.6].

[15] At The Great Chicago Fire of 1871, 18000 buildings including the entire city centre were destroyed. After the fire reconstruction began immediately. The extensive program of this reconstruction process was the opportunity to develop a new form and technique of building.

The structures that were concentrated in Chicago at the end of the last century referred as the Chicago style or Commercial Style of the First Chicago School[16]. The shift from masonry bearing walls to steel framing on concrete footings and foundations with lightweight curtain walls, and the introduction of fire-protected steel were hallmarks of the school [2.7]. In this style it can be seen the application of the international functionalism, of which Viollet-le Duc was one of the first exponent [2.8]. Whereas load-bearing masonry walls admitted relatively few windows, the new structural skeleton permitted more light. The style's character derives from its fenestration, which are large divided rectangular windows so called ‘Chicago window’.

2.3. The Historical Overview

2.3.1. Early Development of the Skyscrapers-The First Skyscraper Period

Fig. 2.3: Home Insurance Building

The early development of the skyscraper occurred in Chicago from about 1880 to 1900 and the Home Life Insurance Company in Chicago (built in1885 and demolished in 1931) is considered as the first skyscraper. The significance of the building rather lies in the technology that has been used. The ten story building, designed by William Le Baron Jenny, was the first high building to utilize the metal skeleton and the curtain wall. His design criteria were: utmost economy of construction, open interior space with space-saving structural solutions, maximum durability, fire resistance, and maximum admission of natural light [2.4].

Jenny discovered the appropriate application of skeleton construction by solving the particular problems of light and loads appearing in this building [2.9]. He used the wrought-iron I-beams for the first six floors and for the first time Bessemer steel beams and girders above the sixth floors of his structure. Jenny’s decision was considered as courageous as Eiffel’s, because the long-term behaviour of the material in structures was not yet well known and it was the first use of the material

[16] The term Chicago School refers to the architects and engineers who were active in Chicago from the time of the great fire of 1871 to ca 1912. The best known of those architects included William Le Baron Jenney, Adler, Louis H. Sullivan, John Wellborn Root, and Daniel H. Burnham.

for a building [2.10]. Their efforts evidenced a will to discover a new style based on avant-garde techniques [2.8].

Without any bearing walls, the entire building weight was carried by the metal skeleton. They were hung from the frame like a curtain [2.1] and every piece of iron was protected from fire by masonry. The method of supporting each bay of the wall on a shelf angle fixed to the spandrel girder and the introduction of steel into the building frame were advanced features of this building [2.4]. The piers were reduced to a minimum in width and weight by taking the floor loads on exterior columns. The aim was to obtain a large number of small offices with maximum admission of natural light. In the *Inland Architect* for November, 1891, Jenney says about the Home Insurance Building; *"It was necessary to make the piers narrow for light and light (in weight) on account of the foundations (nature of the soil); a column in each pier furnished the natural solution."*

Fig. 2.4: Demolition photos of Home Insurance Building

The first two stories were of solid rock faced granite backed with tile, above the granite facades of the building were of red pressed brick that unvitrified with continuous stone sill and lintel courses confining spandrels of brick or terra cotta17. Heavy stone belt courses of cornice type extended the full length of the street fronts at the fifth, eighth and tenth floors. Each bay contained a pair of windows separated by ornamental cast-iron mullion. On the outside elevations the structure was expressed by using plate glass windows within the skeleton framework. The building facade did not express the skeleton-skin concept, but rather that of the traditional load-bearing masonry piers; it is organized in rectangular cells [2.9]. The

[17] Terra cotta; is a light and fireproof material that could be cast in any shape and attached to the exterior, often used for decoration. Jenney advocated using terra cotta to its fullest potential; he recognized the significance of new materials to new types of architecture. In response to the demand for fireproof skeleton construction in Chicago, he advocated a new method of manufacturing process for terra cotta that would meet those demands. It included the use of machines to rapidly and economically produce standard pieces of terra cotta, and a craft process for forming ornamental pieces by hand. The use of strong, hollow, light weight terra cotta as fireproofing and exterior cladding for the steel frame would bring new façade solutions [2.11]. Terra cotta had the potential to liberate skeleton construction from its dependence upon bulky and archaic masonry forms, and would permit a substantive architectural expression for the new office building type.

horizontal grouping, like cornices produced an elevation of building as if it had been constructed in stages. Like the early examples of the skyscrapers occurred in Chicago, Home Life Building represents this model with its above mentioned properties.

In solving the particular problems of light and loads appearing in this building the true application of skeleton construction to the building of high structures is discovered and utilized for the first time its special forms. This building was the culmination of a century's progress in iron-framed construction. It did not embody all the features of the fully developed skyscraper. However, it had the essential features to allow much taller structures than had been possible with masonry construction. The early buildings are all more or less transitional and experimental and each is impacted from the experience of the previous and put its contribution in the development of the idea [2.9].

The ever increasing height of buildings had a great influence for searching an appropriate compositional solution. Jenney and his fellows in Chicago were well aware of the aesthetic problems created by this growing height. They succeeded in creating a new architectural style (Commercial/Chicago style) that represents a building form which derived its character from the industrial and scientific culture of the age and had no counterpart in the past.

Louis Sullivan, one of the leading figures of this style, was convinced that technology represented a meaningful component of design. He believed that skyscraper must express the nature of the construction, the idea of height, and the spirit of industrial society. His forms derived its character from the industrial and scientific culture of the age and to him the ornamental system was inseparable from the building itself. The design of the skyscraper should be the creative translation of structure and plan into appropriate cladding and ornament; however the answers were not to be found in the rules and practice of the past [2.12].

In his 1896 essay "The Tall Office Building Artistically Considered," he advised that the universal law "form ever follows function" should be applied to high rise structures. The understanding of the word "function" is the key to his whole

Fig.2.5: Wainwright Building

Fig. 2.6.: American S. Building

Fig. 2.7.: Tacoma Building

philosophy. It means the design was dictated by the demands of function and structure, not by abstract rules of regularity and symmetry [2.2]. He formalized a vision of a tall building based on the parts of a classical column, involving a base, shaft, and capital composed of certain grouping of stories. In the early 1890s this so called tripartite system, which considered as a new compositional solution, is widely accepted[18]. By employing the tripartite system, Sullivan tested his ideas in the Wainwright Building and the Guaranty Building. In the eleven-storey Wainwright Building in St. Louis [1891], Sullivan with his partner Adler, used a fully developed steel frame [2.1].

The composition was dictated by function and the desire to achieve a “soaring” effect in a building of such height [2.6].The two-storey base of the classical tripartite composition is faced in fine red sandstone set on a two-foot-high string course of granite. The middle section and the top are faced in an ornamented terra cotta skin. The idea that terra cotta gave skeleton construction an authentic architectural expression, found fullest realization in Sullivan’s design for skyscrapers [2.11]. Like the Wainwright also in Guaranty building, the values of the past were more or less included [2.12].

The tripartite concept is well illustrated by the American Surety Building in New York (1894-96) by Bruce Price (Fig. 2.5), with three-story base, an eleven story shaft, and a tall capital. It is also considered as a prototype for the freestanding tower skyscrapers of the early twentieth century [2.2].

The 13-story Tacoma Building (Fig. 2.7) in Chicago [1889-demolished in 1929], by Holabird and Roche was the first building to express skin and an open facade. The building was instead of a tripartite system composed of horizontal layers defined by the floor structures. The most impressive quality is the lightness and transparency of the façade. That is obtained by the projecting bays, along with the extensive

[18] Montgomery Schuyler, who is the reputable and influential architectural critic at that time, wrote an article in 1899 called “The Skyscraper Up-to-Date”, in which he determined that architects seemed to have settled down to a tripartite formula and these may be clothed in a variety of historic styles[2.2].

Fig. 2.8.: Park Row Building

Fig. 2.9.: Reliance Building

transparent area. It represented the rational expression of scientific features of construction and functional design. The using of riveted connections for the first time made a great improvement in the speed and efficiency of construction[19] [2.4].

Vertical grouping of design was still in use after the introduction of tripartite façade design. The 30-storey Park Row Building (Fig. 2.8) in New York (1899) was the tallest skyscraper in the world from 1899 until 1908, when it was surpassed by the Singer Building. The vertical grouping produced a monotonous elevation [2.2].

The structural culmination of the Chicago school came with the Reliance Building designed by C. B. Atwood of Burnham and Company in [1894-95]. Architects employed the new aesthetic feature, the lightness and transparency, steadily and this 14-story building in Chicago represented this feature. The internal floor system is revealed by horizontal window bands that are almost completely glass. The whole bay which is filled by single large pane of glass represented the mature development of the "Chicago window“[20]. The material of the narrow bands is glazed terra cotta tiles, without bearing capacity and the glass is set nearly flush with the spandrels. It has no piers or columns in the exterior envelope. A series of parallel, horizontal slabs carried to the columns by the girders and joists. Structural and functional approach of the Chicago School was represented in this building by its modern dematerialized curtain wall. This building is generally considered as a forerunner of the all glass skyscrapers such as the work of Mies van der Rohe in the 1920's.

The Carson Pirie Scott Department Store (Fig. 2.10) designed by Sullivan in 1904 in Chicago is defined as the ultimate achievement of the Commercial Style. It is

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[19] The riveted and wind-braced steel frame was the creation of the Chicago builders in the period of 1880-1900.[2.4]

[20] Sigfried Giedion, *Space, Time and Architecture* (Cambridge, Mass.: Harvard University Press, 1941), p. 310., -Carl W. Condit, The Chicago School of Architecture (Chicago &London: The University of Chicago Press, 1964), p.111.: Giedion wrote in 1941, "Ten years' experience lies behind the understanding treatment of the horizontally proportioned 'Chicago windows.' In earlier office buildings of the Chicago school the bow windows tend somewhat to be independent and isolated parts of the design. In the Reliance Building they project no more than they are required to in order to pick up light. They are wholly incorporated into the glass body of the building."

mostly a steel-framed structure, but the frame includes cast-iron columns. The street elevations present a dynamic revelation of the iron and steel cage that carries the building loads. It exposes the static of the frame clad with white terra cotta. The spans and heights of the skeleton bays were determined by functional requirements. The elevations have a clearness that represents the precision of science and technology. The building is an impressive expression of modern architecture [2.1].

Fig. 2.10.: The Carson Pirie Building

During the early years of the skyscraper's design, the expression of the frame in the exterior was not the main concern. After the well established steel skeleton use (by the mid-1890s) the appropriate expression of the new structural system, the expression of the frame in the exterior design, became an important concern. The use of the skeleton metaphor in relation to architecture was not new in the late 1890s. Viollet-le-Duc brought a rational analysis to construction that has had a wide influence in architecture in his writings. Viollet-le-Duc had been concerned with what he termed the "skeletal" construction of Gothic structures and correlated the Gothic cathedral with the human frame. [2.13-6].

2.3.2. Skyscrapers in the Early 20th Century- The 2nd Skyscraper Period

Toward the end of the 19th century, the ever increasing height of buildings forced designers to search for an appropriate compositional solution. The tripartite system became outmoded and as building height increased, the problem of relating the parts to the whole became harder. The philosophy of Chicago School, lightness and transparency of the façade through new technological solutions and the expressing of function, were not accepted in New York. New York designers were bound to the architectural styles and they preferred eclectic forms. The eclectic phase produced remarkable monuments, employing many of the styles and ornamentation from the past [2.10]. The order of past styles from Classic to Gothic periods attached to the steel frame and disguised it. Gradually tall towers had replaced the relatively low building blocks, and defined the skyline and the silhouette of the cities with their symbolic roles.

Chicago's leadership in high-rise construction had stopped short in 1893 because of financial panic. The building height was limited by city council to 130 feet, the

Fig. 2.11:Singer Building

Fig.2.12: Metropolitan Building

equivalent of ten or 11 stories, this time technical components were not the determinants in restricting building height. After this ordinance passed in Chicago New York City took the lead because in New York counter to Chicago height was unrestricted. From 1870 to 1913, New York turned to a city of five- and six- story buildings to a mega-metropolis with fifty story towers [2.14].

Towers could increase rapidly with the metal-skeleton construction admission by the building code after 1889. By 1913, in Manhattan there were nearly one thousand buildings of eleven to twenty stories, and fifty-one of them were between twenty-one and sixty stories. One of the main reasons of this development was the population growth of New York. It was slightly more than double of the Chicago’s population in 1920 (5.6 million versus 2.7 million residents) [2.15].

Towers were seen as possible solutions for the design of the new tall and ever-taller skyscrapers during the 1890’s. The first towers like buildings were erected about 1895, and the American Surety Building (1894-96) considered as the first free-standing tower building.

Within a few years the buildings continued grow even taller and the beginning of the second skyscraper period is marked by the Singer Building (1908), designed by Ernest Flagg, with 53 stories(fig.2.11), and Metropolitan Life Insurance Building(1909) , by Napoleon Le Brun and Sons, with 52 stories (fig.2.12). They were both designed in the classical form.

Woolworth Building [1913], erected by Cass Gilbert, was the world's tallest[21] building of its time with 57 stories. The Woolworth Building had also its tower set on a broad base like Singer and Metropolitan Buildings. This tower-with-base formula solution was the revision of the N.Y. building code in 1916[22]. The code

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[21] With 792 ft in height, was to remain the world's tallest building for seventeen years before the 77 -story Chrysler Building was completed.

22 The period began in 1916, its heyday was in the 1920’s, between the end of World War I and the depression of 1929.[2.2] attempted to control the impact of gigantic buildings upon the urban environment by defining the maximum building envelope for each lot, so as to protect the light and ventilation of adjacent sites. The new building form that the code produced was the setback tower [2.1]. Originally instituted only as restrictive

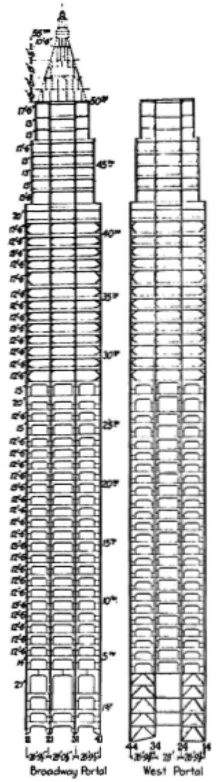


Fig.2.13: Woolworth Building The structural schema

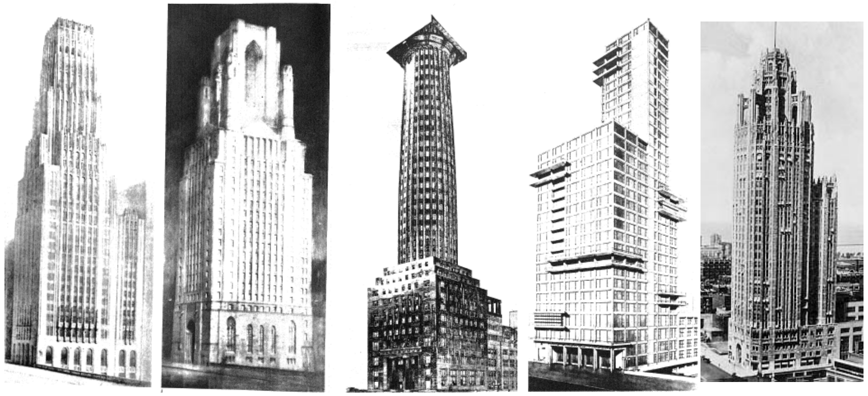
introduced a zoning ordinance that necessitated a set-back system based on the width of the street [2.2].

Woolworth building often called the Cathedral of Commerce because the Gothic style of the cathedrals was successfully introduced as a model for skyscraper design with this building. It consists of three parts: the massive 27-story base, the 30-story tower, and the spire. The central piers on the front facade rise from the bottom to the crown. The building’s facades are everywhere fully finished; the screen-like walls with their ornament perfectly express this upward-soaring. For Gilbert, the Gothic style was optimally expressing the vertical lines of the tower form [2.1]. Above the granite-and-limestone-covered base, ivory-colored terra-cotta selected as the cladding material and it could be applied thinly and molded and colored effectively [2.14]. In Gilbert’s terms, the steel frame was “enriched and beautified” by its cladding. Gilbert’s treatment of the terra cotta envelope incorporated the thought and practice of the day regarding the appropriate use of terra cotta for the exterior of steel-framed skyscrapers [2.11].

This decorative façade structure does not articulate the order of the building support structure. Against the turbulent winds of New York, heavily braced steel frame keeps the tower rigid. The wind-bracing of the riveted frame is for the most part a system of portal arches. The arched frame of the Woolworth tower extends up to the twenty-eight floor; above this, to the forty-second floor, bracing is secured through a double system of knee braces. The architectural design of the Woolworth was certainly affected by aesthetic considerations, but it was influenced by economic reasons as well. To produce the maximum income the building had to fill up as much of the lot as possible, thus it had to have “many windows so divided that all the offices should be well lighted.” [2.14].

There were strong debates among architects about the development of a style appropriate to the tall building’s structural system. Gothic with its soaring vertical

legislation without any aesthetic aim, in the 1920s zoning became the principal inspiration behind a new style in skyscraper design and a new vision of the modern metropolis [2.16].



1 2 3 4 5

Fig.2.14.Chicago Tribune Tower Competition Design Entries

1- *First-prize design by Howells and Hood, United States*
2- *Second-prize design by Eliel Saarinen, Finland*
3- *Third-prize design by Holabird and Roche, United States*
4- *Entry by Adolf Loos, Austria*
5- *Entry by Walter Gropius & Adolf Meyer, Germany*

elements is considered as suitable for creating a stylized mask to clad the high-rise [2.17]. The strong image and influence of the Woolworth Building was seen in the Chicago Tribune competition of 1922, which was won by Raymond Hood's gothic revival design (36-story building, completed in 1925). Its Gothic style is regarded as a transitional phase in skyscraper design [2.13].

This famous international competition for the Chicago Tribune Tower demonstrated the eclectic phase and also stimulated the further development of the skyscraper design. It drew more than two hundred submissions from twenty-three countries. The entry by Walter Gropius and Adolf Meyer expressed the radical modernism with the structure and function relation and the representation of technology. It can be seen as an advanced stage of Sullivan's Carson Pirie Scott Department Store[23]. This modernist view had already been taken further by Mies van der Rohe in his glass skyscraper projects of 1920 [2.1].

The effect of the revision of the New York building code in 1916 can be seen in Saarinen's entry. The stepped-back building seems to grow out of the ground organically [2.1]. Although the ornamental treatment is entirely vertical it is not as intensive as Gothic, it is more personal and artistic. Saarinen’s entry considered more influential on American architecture than other entries. The selection of a gothic style design extended the eclectic style against the concepts of the modern.

European Modernism had not yet taken the field in America and architects of the 1920s were searching for decorative solutions for skyscrapers. In the ever-larger office skyscrapers of the 1920s, American architects moved from historic detailing to more original and abstract art deco detailing.

[23] Sigfried Giedion in his book “Space, Time and Architecture” described them *“two stages in the development of the same set of ideas.”* He assumed that Gropius’s entry served as a verification of the spirit’s universality [2.13].

Fig.2.15: Chrysler Building

The modernist approaches and the reduction of ornament by integrating art, architecture, and a personal philosophy Art Deco[24] style evolved. Art Deco ornament was considered as modern, stylish, and appropriate for machine production. Art deco skyscrapers generally considered as modernistic instead of modernist. Clothing is the main feature of the Art Deco skyscraper; spires, pinnacles and crowns were used [2.18, 2.1].

The most famous Art Deco skyscraper is the 70-storey Chrysler Building by William Van Alen in New York (1928-30). Its facade architecture uses modern form language with a composition of industrial design concepts. On the lower storeys relatively large apertures are placed at regular intervals. Soaring verticality was achieved by enclosing slabs and conventional vertical brick piers. The façade displays a decorative detail, its crown-like dome of stainless steel, with tiered arches filled with sunbursts and capped with a spire [2.18]. Other ornamental features include symbols of the automobile industry like eagle gargoyles [2.1].

Even though the heights of skyscrapers were significantly increased during this period, most of them had the same structural solutions. They were constructed with steel rigid frames with wind bracing. The enormous heights were achieved through excessive use of structural materials. The buildings were quite over designed because of the absence of advanced structural analysis techniques [2.19]. Reinforced concrete was used only for lower buildings. It was not until the 1950s[25] that reinforced concrete, as a material and structure, established its own identity in tall buildings construction [2.1].

[24] Art Deco takes its name from the *Exposition Internationale des Arts Decoratifs and Industriels Modernes* – held in Paris 1925. Style: consciously strove for modernity and artistic expression to complement the machine age. An emphasis on the future rather than the past was the style's principal characteristic. Art Deco offered, if not a machine-age esthetic, a means to celebrate both art and technology [2.18].

[25] In 1962, the 60-story Marina Towers in Chicago by Bertrand Goldberg, reached 588 ft. These may be considered the first true reinforced concrete skyscrapers expressing the character of the material [2.1].

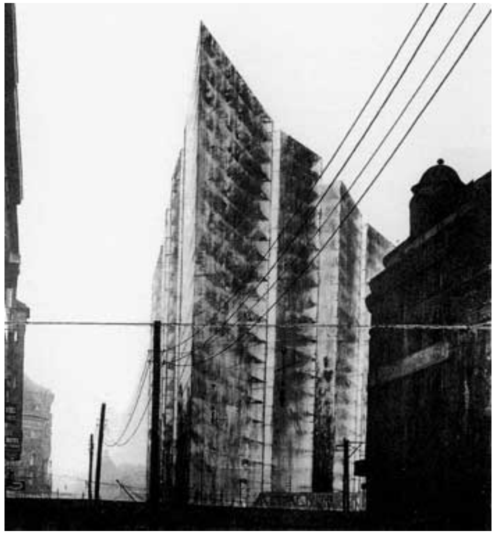


Fig.2.16: Mies van der Rohe’s Glass Skyscraper

2.3.3. Skyscrapers and Modernism -The Third Skyscraper Period

Modernism determined the third skyscraper period. Tall buildings were built not just in steel, but also in reinforced concrete and masonry. Cubic building volumes, flat roofs, horizontal window bands and parapets, white stucco façades, and lack of ornamentation characterize the modernist or International Style. Construction had become one of the prime motivations of the form-giving process by using an approach derived from functional and technological facts[26]. Modern buildings’ forms should express the potentialities of the time. Their materials and structural engineering between artistic expressions and technology should be established in a modest artistic architecture [2.24].

By about 1930, some European modern ideas begin to appear in New York but actually European Modernism developed in the 1910s and the 1920s. With Gropius and Le Corbusier, Mies was one of the major figures of the Modern Movement. For Gropius the true aim of contemporary architecture is to define the norms of industrialized products. By 1925 he had clearly set out the problem of integrating the arts and technology[27] into architecture. He advocates of the aesthetics of functional beauty. Mies van der Rohe, who emerged from Gropius’s entourage, had the same philosophy. Mies saw two driving and sustaining forces: economics and technology. „*Whenever technology reaches its true fulfilment, it transcends into architecture.*“ To him only if architecture was fully responsive to such forces could it hope to give expression to an epoch [2.8-20-21].
In 1922, Mies wrote the following lines:

“*Only skyscrapers under construction reveal the bold constructive thoughts, and then the impression of the high reaching steel skeletons is overpowering. With the raising of the walls, this impression is completely destroyed; the constructive thought, the necessary basis for artistic form-giving, is annihilated and frequently smothered by a meaningless and trivial jumble of forms… and yet these buildings*

[26] This approach was similar with the commercial style and the first skyscraper period buildings.
[27] This recurrent French view of the interaction of architecture and technology, expressed earlier by Henri Labrouste and later by Auguste Perret. [2.20]

Fig.2.17: Lever House

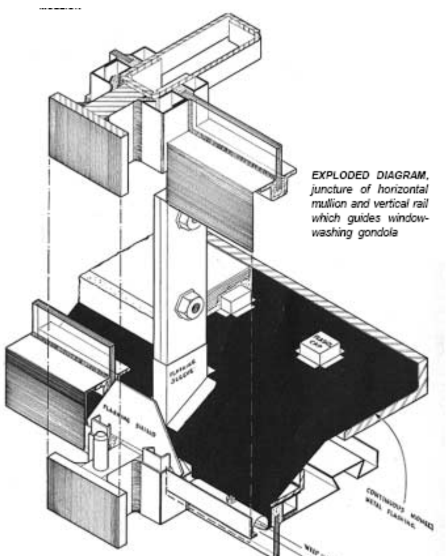


Fig.2.18: Curtain wall detail of Lever House

could have been more than just manifestations of our technical skill. This would mean, however, that one would have to give up the attempt to solve a new task with traditional forms-, rather one should attempt to give form to the new task out of nature of this task."

Mies was interested in designing buildings that would be so devoid of ornamentation and so unconcerned with architectural form that they would be simply expanses of space, separated from the exterior surroundings only by large glass surfaces. His slogan "Less is more" exemplifies this quest. Mies van der Rohe's Glass skyscraper design entry for the 1921 Friedrichstrasse Skyscraper competition was an angular twenty-story office tower with a skin made entirely of glass based on the supporting steel skeleton structure. Its high ceilings and liberal use of glass allowed light to penetrate deep into the center of the building. The design anticipates Mies's later preference for steel and glass. He was fascinated with the possibilities of the technological revolution and his vision of a glass curtain wall inspired architects designing tall buildings all around the world.

After the Depression and then World War II, the tall buildings (they were called as high rise buildings) were begun to be built again firstly in the early 1950s. The modernist, or international, style becomes synonymous with glass towers. The real breakthrough in glass technology is occurred after the Second World War with the float-glass process[28]. The interaction of economic, technological and stylistic factors now contributed to the rapid spread of the use of glass as a building material.

The two early examples of modernism in tall building architecture built in New York; these were Lever House and Seagram Building. Lever House, designed by SOM in 1952 on Park Avenue in New York, establishes the idea of European modernism with its clear glass and its blue glass panels that set at a right angle to the street.

[28] In 1952 Alastair Pilkington invented the float process. This new invention takes the flat glass technology to a revolutionary new level. He conceived the idea of forming a ribbon of glass by floating the melted raw materials at high temperature over a bath of molten tin. It took seven years and £80 million in today's money to develop the process [2.22].

Fig.2.19: Seagram Building

Lever House has been described as "one of the first successful commercialisations of the Mies van der Rohe geometry of metal and glass."[29] Gordon Bunshaft, the chief designer for the project at SOM, proposed a narrow office building in glass and steel, raised on a horizontal base, with an open area, supported by pillars. Thus, openness of the ground floor served as a public space. 24 story building has blue-green heat-resistant tinted glass without an openable sash. Wire-glass faces the spandrels are of masonry because of the building code. The structure itself is of conventional steel frame, with tower bays so laid out that only narrow vertical mullions, formed of paired channel shapes, interrupt the glass [2.23].

Together with Seagram Building, Lever House impacted the zoning regulations of New York City. Skyscrapers with plazas open to the public become a common design solution. Rapid mechanisation of the building industry offered new materials and building techniques. Besides the complete air conditioning, the building is fitted with what has been defined at that time "the most modern fire alarm equipment"[2.23].

The Miesian glass architecture and its flat facades, proportions became a prototype in tall buildings throughout the world during the post-war years. Characterized by functionalism and direct expression of materials and structure, modern high-rise office buildings have become corporate icons [2.24].

[29] Jacobus, John, *Encyclopedia of Modern Architecture*, New York, 1964, p.23.

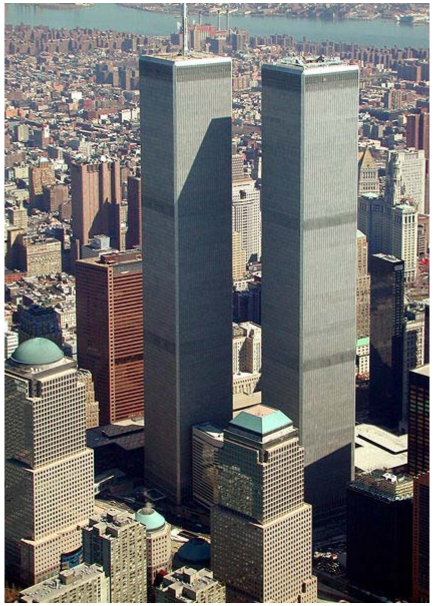


Fig.2.20: World Trade Center

2.4. Structural Developments

The mid-twentieth century, after the Second World War, tall buildings' design based on the International Style defined already before the war, and the technology developed earlier. Economy was the major driving force of tall building's mass production and developments [2.25].

By the early I970s significant engineering developments occurred. The common type of structural system for steel or concrete tall buildings began to change. Fazlur Khan, from Skidmore, Owings & Merrill (SOM), created new structural solutions for tall buildings that opened up new and exciting possibilities for tall building design. With the advent of high-speed computers rational structural analysis was possible, which has never been possible before. Computer simulations made possible the building analysis in three dimensions and the mechanics of material and member behaviour understood better. Khan reasoned that the structure could be treated in a holistic manner [2.25]. He realized that the demand on the structural system increased as buildings became taller because of the lateral loads (wind and earthquakes). Thus, the total structural material consumption increases. However, lighter tubular structures made the structural systems for tall buildings more efficient and economical. Because of the three-dimensional response of the building to lateral loads the skeleton provides greater lateral resistance in tubular building concept. Structural members can be expressed directly on facades in these tubular concepts. Tubular structures have different configurations such as the framed tube system which employed in World Trade Center [2.24].

The tube-units could take on different shapes and could be bundled together in different groupings. The new solutions of exterior structures can create a type of aesthetics, the so-called structural expression expounded by Fazlur Khan and others [2.24]. Khan's two internationally famous designs are the John Hancock Center and the Sears Tower in Chicago. Different and innovative concepts of structural forms are used in these buildings. A braced tube system for John Hancock Center and a cellular bundled tube system for Sears Tower were used. Both buildings show the structure clearly, the structural form directly influencing the architectural aesthetic.

Fig.2.21: John Hancock Center

Fig.2.22: Sears Tower

Bruce J. Graham (chief architect) and Fazlur Khan(structural engineer) from SOM designed braced-tube (is variation of a framed tube) structural system for Chicago's 100-story John Hancock Center. The multi-use tower, completed in 1969, has a remarkable design, with the huge X-braces[30]. The fully exposed giant diagonal braces on the façade are its most striking structural features. All of the exposed details of the building are held together by these diagonals. The main vertical columns and the horizontal ties at the intersection of each X-brace are also expressed. The exterior columns and spandrel beams, together with the diagonal members and structural floors, create the steel tube. As a fully integrated expression of form and structure, the braced-tube structure maintains its character of strength and permanence. The innovative construction decreased the required steel compared to traditional solutions. The exterior cladding is black anodized aluminum with tinted bronze glass [2.26].

Sears Tower is another SOM designed tower with 110-story and 442 meters height. It was the world’s tallest building from 1973 to 1998. The Sears Tower is a bundled-tube structural design. The rigid outer walls act like the walls of a hollow tube. It is actually a bundle of nine tubes which designed efficiently to withstand wind. This design for Chicago's Sears Tower was structurally efficient and economic: The bundled tube concept allowed for wider column spacing in the tubular walls. it provided more space[31] and rose higher than the Empire State Building, yet cost much less per unit area. This expression of each tube’s independence is contrasted by the mechanical levels, which are placed at the same level on each tube. Steel belt trusses enclosing these levels wrap around the building, bundling the individual tubes together. The mechanical levels also cap many of the tubes. Clad in black aluminum with bronze-tinted glass.

[30] Although diagonal bracing members were used in early tall buildings to resist lateral loads; they were embedded within building cores in the interior [2.25].

[31] As the system of business became bigger and as new scientific management systems emerged, the demand for open space increased[2.19].

Tubular forms have several types depending upon the structural efficiency that they can provide for different heights. Other structural alternatives include superframes, telescopic tubes, or a hollow megatube structure [2.25]. Beginning in the 1980s the new generation of tall buildings broke the monotony of the exterior tower form. Miesian tall buildings were replaced by the facade characteristics of postmodern32, historical, diagrid and high-tech expressions. With new technologies tall building structural systems have become much lighter than earlier ones. Although there are many structural design alternatives for tall buildings, only some structural systems have had major impacts on the building aesthetics. The most popular structural systems for tall buildings are various tubular structures, core supported outrigger systems and diagrid structures [2.25]. Buildings that exhibit strong structural expression and employ the above mentioned structural systems presented primarily. The technological and architectural components of their facades are inseparable in these buildings; they are complementing each other [2.24-25].

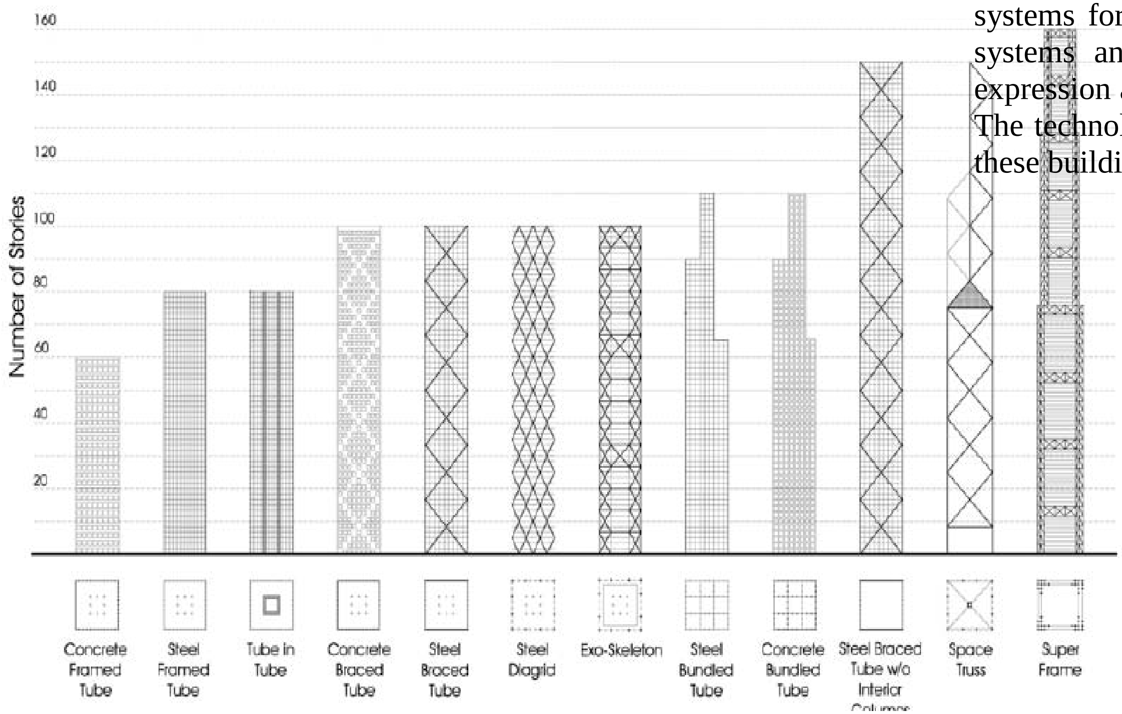


Fig.2.23: Exterior Structures

[32] For Post-Modernism, Art Deco again became a strong source of inspiration and brought back the early skyscraper image [2.1]. Various traditional architectural forms are used as a reaction to modernism in early 1980s. AT&T building by Phillip Johnson(1978-84) is generally considered as the first post-modern skyscraper.

Fig.2.24. Swiss Re Building

Fig.2.25: Hearst Tower

Fig.2.26: Lotte Super Tower

Fig.2.27: China Central Television Building

2.4.1. Diagrid Structural Systems

The world of engineering and design is changed by computers. Digital technologies allow creating and fabricating innovative designs. The perceived boundaries of possibilities are expanded. Diagrid (diagonal grid) structure is another version of tubular systems. The use of diagonals and the aesthetic potential of them have generated renewed interest by tall buildings' designers. They are considered as structurally efficient and architecturally pleasing structural systems. Diagonal bracing members were used in early tall buildings to resist lateral loads; they were embedded within building cores in the interior. In current diagrid structures, they are located at the perimeter of the building where the major lateral load resisting is provided and they can also carry gravity loads. Therefore the conventional vertical columns can be eliminated. The aesthetical expression of these solutions on facades of the tall buildings is also significant [2.25].

The Swiss Re Building (30 St. Mary Axe) in London (2004) is one of the first, iconic, large scale diagrid structures (Fig 2.24). Foster and Partners was architect on the project; the engineer was Arup. The key feature of the design is the diagrid system; it consists of diagonal columns and horizontal hoops. The building raises forty-one storeys. The diagonally braced structural envelope allows column-free floor space and a fully glazed façade. The glass facade is made of flat panels although the building appears round.

46 stories Hearst Tower (2006) in New York is also designed by Foster and Partners. At the Hearst Tower each triangle in the diagrid is four stories tall. It rises from the six-story base of a landmark art deco building. The diagrid frames of the tower contain roughly 20% less steel than would a conventional perimeter frame (saving~2000 tons of steel).

The Lotte Super Tower in Korea is another ultra-tall building which employs a diagrid multi-planar façade. The tower is currently being designed by Skidmore, Owings and Merrill, it will be 555 m tall [2.25]. The diagrid structure of the tower is optimized with steeper columns at the base to best respond to gravity loads and shallower columns at the top to best respond to lateral wind forces.

Fig.2.28: COR Building

Fig.2.29: O-14 Building

The external diagrid structure is boldly expressed in the building's façade of the China Central Television new headquarters building (CCTV) at a height of 230 m. It is designed by the Office for Metropolitan Architecture (OMA) to be completed for the Beijing Olympics in 2008. The seismic stability, which is highly desirable feature in Beijing, is achieved through the diagrid framing of the external tube structure. The internal structure is supported by vertical steel columns and cores. All the structural support elements in the building are of structural steel, except some external columns are steel-reinforced concrete columns [2.28]

Like in the above mentioned examples, in diagrid steel structure, they express their regular diagrids on their facades. Another new design approach uses reinforced concrete in structural diagrid patterns instead of steel. Thus, new architectural aesthetic expressions are emerged which are different from that generated by steel structures. Because of the material features of concrete, more fluid and irregular structural diagrid patterns can be created. These are different from the explicit and pristine feautures of steel diagrids [2.25].

Both the COR Building in Miami (estimated completion 2011) by Chad Oppenheim Architecture and Ysrael Seinuk of YAS Consulting Engineers and the O-14 Building in Dubai by RUR Architecture (estimated completion 2009) employ reinforced concrete diagrids as their primary lateral load-resisting systems. In O-14 Building a core works with gravity and concrete diagrids takes the lateral forces. Over 1000 circular openings of the concrete diagrids have different scales ranging from 2.5 to 6.5 meters, which could work also as a sun screen [2.29].

Fig.2.30: Landmark Tower

Fig.2.31: Jin Mao Building

Fig.2.32: Petronas Tower

Fig.2.33:Taipei 101 Tower

2.5. Contemporary Design Strategies and New Forms

As the below statistics shows, the most active tall building development has been shifting from North America to Asia. This trend can be seen in notable recent tall buildings such as the Jin Mao Building, Petronas Towers in Kuala Lumpur, Landmark Tower in Yokohama, and Taipei 101 Tower.

Region	Buildings	Percent
Asia	38564	30.6%
North America	31102	24.68%
Europe	27575	21.88%
South America	24508	19.45%
Ocenia	2978	2.36
Africa	1289	1.02

(2008based on most active cities in the regions reported in *Emporis.com*).

These buildings have their own regional images. Although they have inspired from traditional architecture they are the products of contemporary technology. Tubular structures are used in Landmark Tower which is the tallest building in Japan, is designed by H. Stubbins & Associates (1993). The core supported outrigger structures are used in the Jin Mao Building designed by SOM (1998) in Shangai and Taipei 101 Tower (2004- 508 m with 101 stories) in Tapei designed by C.Y. Lee & Partners. Petronas Towers which designed by Cesar Pelli were the world's tallest buildings from 1998 to 2004 until Taipei 101 [2.30].

Appropriate choice of building form moderates wind responses. Aerodynamic modifications are another recent design approach of tall buildings. These modifications can reduce the effect of the lateral wind force. This can be achieved by various treatments of building masses and forms [2.25]. An appropriate building shape can result in a significant reduction of aerodynamic forces by changing the flow pattern around the building [2.31]. Examples employed in contemporary tall buildings are the tapered cross section, setback, sculptured top, modifications to

Fig.2.34: The Shangai W. F. Center

Fig.2.35: Al Mamlaka Building

corner geometry (chamfered or rounded), and addition of openings through building, and notches.

The Shanghai World Financial Center and Al Mamlaka at the Kingdom Center in Riyadh employ a large through-building opening at the top combined with a tapered form. Kingdom Center in Riyadh (2002) rises to 300 m high designed by Ellerbe Becket, Omrania and Associates.

The Shanghai World Financial Center (2008) designed by Kohn Pedersen Fox & East China Architecture and Design Institute. 101 story building rises to 492 m. The mega structure consist major structural columns, the major diagonals, and the belt trusses. The concrete core walls and the perimeter mega steel frames form the lateral system of the structure. It holds two tuned mass dampers to reduce the building's sway during windstorms and earthquakes.

Structural measures alone are sometimes not enough to find a practical solution to motion problems. Therefore other approaches such as special damping devices must be used. There are various damping strategies which employed to reduce the effect of wind loads applied to tall buildings. Some of the above mentioned examples also have different damping devices but it is not the scope of this study. The developments which have direct impact on the building aesthetics are examined primarily [2.31].

Aerodynamic forms in general reduce the along-wind response as well as across-wind vibration of the buildings caused by vortex-shedding by "confusing" the wind [2.25].The aerodynamic modifications besides from tapering lead also to twisting and other building forms with discontinuities and multi-planar façade solutions.

Fig.2.36: Turning Torso Tower

Fig.2.37: Chicago Spire Building

2.5.1. Twisted Forms

Increasingly, twisted forms become a new design approach in tall buildings. It can be considered as a reaction to boxed shaped of modern architecture [2.22]. Actually this type of design is not new in architecture. Numerous twister shapes have been designed [2.32].

This twisted form can be found again in contemporary architecture. Since 1990 twisted forms projects appeared in competitions and feasibility studies all over the world. The common parameters that vary are shape of floor, direction and degree of rotation, and the scaling of floor plans in one or two directions. All these designs combine new technical achievements with new shaping. CAD, CAM and CAE (computer aided design, manufacturing and engineering) play a major role. Twisted forms are effective in reducing vortex-shedding-induced dynamic response of tall buildings by disturbing vortex shedding. These forms are not beneficial in terms of static response.

A contemporary example of a twisted form is the 190m high Turning Torso tower with 54 stories, designed by Santiago Calatrava, 2005 Malmö (Sweden). The 90º twisted tower obtains stability from a central cylindrical concrete core. Most of the weight of the concrete floors rests on the core; the steel exterior profiles are mainly decorative. The twisting form is composed of nine box units, shaped like cubes with triangular tips.

Another Calatrava design with twisted form is Chicago Spire Building (2007/-) which will be 610 m with 150 stories. The 270° twisted building has a square floorplan that scales down to the roof. The ground floor has inward curving sides. Towards the top, the corners have incrementally been cut off along circular lines; the widening corner surfaces meet as a round roof plan [2.32].

Fig. 2.38.: The Le Phare Tower

Fig.2.39: Fiera Milano Building

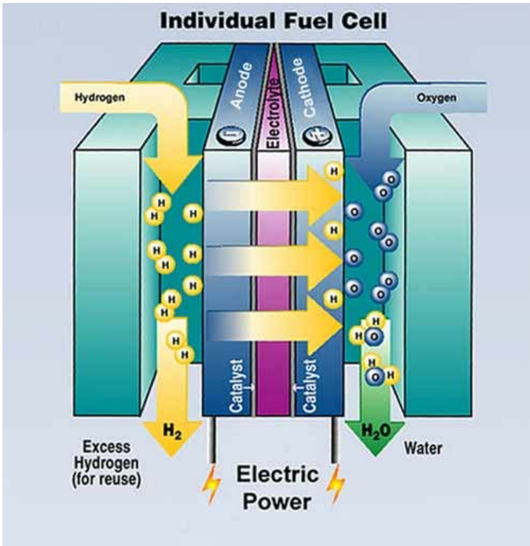
2.5.2. Free Forms

Architecturally, structurally and aesthetically to create an optimal form for tall buildings is a complex task. With new technological improvements, the conventional limitations of tall building design dissolved with structures that taper, tilt and twist. However architects are searching for much more freedom of form.

The capability to translate 3D computer models into production drawings and data for fabrication has continued to grow rapidly. It has allowed much greater confidence in design with more complex geometry with new material features and shows itself as a wide ranging freedom in determining the forms of buildings.
Although the supporting structural systems behind the free form tall buildings can be various depending on the project-specific situations, diagrids are often employed as primary structures.

Some examples are Morphosis' Le Phare Tower in Paris, the Daniel Liebeskind's (in collaboration with others) Fiera Milano Tower, Peter Pran's Oil Company Headquarters in Jeddah and Zaha Hadid's Dancing Tower in Dubai, which are not built yet. The Le Phare (Lighthouse) Tower which is designed by Thomas Mayne (the name of his company is Morphosis) will be 300m height with 68 stories. It is expected to be completed in 2012. The tower's structure will combine a rectangular base with a soaring, organic-shaped tower, capped by a field of wind turbines. In collaboration with Zaha Hadid, Arata Isozaki and Pier Paolo Maggiora, Daniel Libeskind is the master planner redeveloping the Fiera Milano. Construction began in 2007 and expected to be completed in 2014.

Energy efficient design features play an integral part of the design of the above mentioned buildings such as; wind turbines, photovoltaic panels, sensors, smart materials and etc. The detailed analysis of the environmental concerns, its impact on architecture and sustainable design approach, with new technologies is discussed in Part 3.



PART 3. SUSTAINABLE DESIGN APPROACH

PART 3. SUSTAINABLE DESIGN APPROACH

3.1. The History of the Sustainable Design Approach

Fig. 3.1. Our Common Future

The evolutionary change in architectural profession is being driven by the invention of new materials or new industrial tools. For the first time since the rise of modernism the real need to stop harming the natural systems, begins to shift architectural practice. Architects of this century design with different priorities. A popular environmental movement began after the oil crisis of 1973 which had a direct effect on architecture. It has been realized that overall energy use in buildings could be reduced with better design and improved technology.

In 1980, the World Conservation Union published the World Conservation Strategy, which first brought the concept of sustainability to a wide audience. It referred to the sustainable use of resources, the maintenance of ecological processes, and the maintenance of genetic diversity. Although not directly based on architecture, these have direct correlations to the built environment. The Brundtland Report[33], which was published in 1987 "Our Common Future" addressed energy conservation issues and social issues. Dangers of the fast increasing energy demand of humankind highlighted in the Report. The threats were determined as the exhaustion of non-renewable sources of energy and the climate change because of the carbon-dioxide emission involved in the use of certain sources of energy. Sustainable development defined as: *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* [3.1]
After the Rio Declaration[34] in 1992 the issues of sustainable development become studied thoroughly in all the branches of science and technology. The first

[33] The Brundtland Commission, formally the World Commission on Environment and Development (WCED), known by the name of its Chair Gro Harlem Brundtland, was convened by the United Nations in 1983. The Report of the Brundtland Commission, Our Common Future, was published by Oxford University Press in 1987
[34] UNO World Conference on Environment and Development held in Rio de Janeiro in 1992, the Rio Declaration have been published under the title 'Tasks for the 21st Century'. The Rio Conference demonstrated that the implementation of sustainable development was a complex objective. This can

Fig. 3.2. Sustainable Design

international symposium on sustainable construction is organized by the International Council for Building Research (CIB) in Florida in 1994, and there sustainable construction defined as ‘creation and responsible management of a healthy built environment on resource efficient and ecological principles’. Some of these principles are: the quality of indoor air, the amount of energy used for heating and air-conditioning of buildings, waste management, durable and “environment-friendly” building materials, housing for the poor, etc [3.2].

In a world with growing concerns about global energy use and carbon emissions, energy efficient and sustainable building design becomes a necessity. The amount of needed energy for cooling buildings is significantly increasing the CO_2 emission. This leads architects to emphasis more on climate-responsive buildings [3.3]. According to the 2004 World Energy Report the world energy needs will increase by 60% by 2030 with two thirds of the additional needs will come from developing countries, therefore, more emphases on renewable energy are needed [3.3]. Shifts in the profession of architecture are being driven this time by the real need for us to stop harming the environment that supports our existence. To design buildings that enhance their environment, aesthetically pleasing, functional and comfortable are the primary concerns of designers. The synthesis of all of them into single design intent is now at the cutting edge of sustainable building development.

In the last decade, the word “sustainability” represents a balance of economic, social and environmental issues in the way people live. A successful balance between these issues can be achieved by an overall approach to building design. *Free heating, free cooling, day-lighting, rainwater collection, solar power and wind power* are some features that improve the sustainability by using natural elements. [3.4]

3.2. Tall Buildings and Sustainability

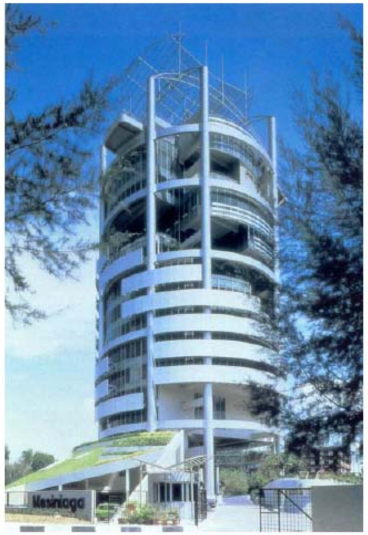
Recent designs have moved towards making the most of the natural resources available and turning them to advantage internally. Buildings of the 21st century should be more sustainable than in the past. They should be responsive to

only be achieved by the participation of all professions, fields of science and the various sectors of economy and society environmental conditions to embrace sustainable development. Because about 25 percent of land waste comes from building construction, 25 percent of solid waste and 50 percent of carbon emissions related to the operational waste of buildings. Additionally construction related activities like mining impact our environment by the destruction of natural habitats [3.5]. The selection of material can make a significant impact in the sustainability of buildings.

The conservation of resources generally requires smaller energy consumption and a reduction in the amount of materials used. It is also expressed by reducing the weight or thickness of structures[35]. These approaches can make economic sense if they improve performance. The ability to predict the performance of buildings has become prominent because of rapidly changing materials, building techniques and equipment. The necessity to conserve global material and energy resources also requires more efficient buildings [3.6]. Recent design approaches and innovations aims to achieve zero carbon opportunities for architecture. By using high-tech materials (like light weight, fiber reinforced composite materials) the embodied energy produced during their use can be minimized [3.5]. A good example of this “dematerialization” is the Carbon Skyscraper Project by Peter Testa Architects which is examined in last chapter. The development of technology can be defined by increasing productivity of labour and capital, better conditions in construction, improved quality, usability, durability, and, conservation of resources to ensure sustainable growth [3.7].

Tall buildings are seen as inevitable building forms because of the global population growth and the increasing rate of urbanisation. The tall building as a building type will continue to be built in cities in the near future, and improving their environmental sustainability grows more urgent because of their scale. Tall buildings with new design approaches can have a crucial impact on sustainability. Improved design solutions, new construction techniques and advances in building

[35] The increase in the quality of material technology over the past 100 years is illustrated by the oft-quoted example of the Eiffel Tower. Whereas when it was built this optimum design in terms of structure and use of material required about 7000t of steel, these days only 2000t would be necessary [2.5].



services make greener buildings possible. Buildings are using 45 percent of non-renewable energy. In London, tall buildings can consume up to 72 percent of non-renewable energy [3.5]. Most of the tall buildings were previously designed 100 % reliant on mechanical air conditioning. Minimizing the energy consumption as much as possible and even generating their own power from renewable sources become new design criterion for tall buildings. They are considered as essential elements in a sustainable or ecologically friendly strategy for urban design. To design an ecologically-responsive tall building is a very complex task For more sustainable tall building there are some design features such as; day-lighting, natural shading, energy-efficient, PV facades, wind power systems, and etc. The combination of such design features is becoming common among architects [3.4].

With the Sustainable Movement, which started in 1970s, architects started to think what needed to be done to effectively decrease energy consumption. One of the most urgent issues at that time was the need to minimize a building's dependence on air conditioning and artificial light, which is still important in sustainable thinking [3.1].

Three main concepts are used in tall buildings; passive, mixed and productive building operational systems. Passive mode design is obtained by using simple cooling, heating and lighting through the building's form and orientation. Building orientation impact building's energy efficiency and can be used for passive cooling and heating techniques [3.5]. By allowing air in and through the internal spaces of the building, natural air conditioning can be achieved [3.4]. The mixed mode design uses partial mechanically assisted systems. In the productive mode design, systems which generate on-site energy are used [3.5]. The use of productive systems such as PVs and wind turbines can supplement passive and mixed operational system by an on-site energy production.
Façades play a determinant role in the energy-efficiency of a building. The need to reduce energy should drive the use of high performance building envelopes [3.4]. Large glass surfaces can significantly reduce the need for artificial lighting. Energy conservation goals have risen and high-performance glazings can provide substantial energy. Double- and triple-glazing, and new types of glass with thin-film technologies reduce energy consumption of tall buildings. An efficient way of

Fig. 3.3. Menara Mesiniaga Building

Fig. 3.4.Commerzbank Building

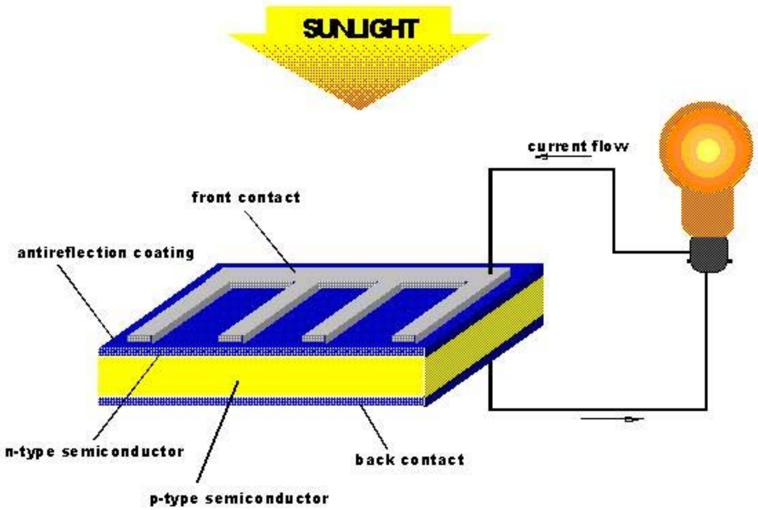
providing light and ventilation can be achieved by automated or user controlled mechanized façades. A variety of glass type and applicative films is also available to enhance the performance of lighting. New responsive glazing systems have positive consequences in terms of climatic response [3.5].

Double skin systems can response to seasonal changes, which can act as a buffer between inside and out. The intermediate space can be used to buffer thermal impacts on the interior and operable shading devices can also be located inside the cavity. Open slots and operable dampers can be used in the glass planes. Therefore, it is possible to ventilate inside the cavity in summer time and admit sun warmed air to the interior rooms in winter time. For an optimum thermal barrier double glazing can be used at the inner façade while a single glazing can be sufficient for the outer façade [3.8]. To develop energy-efficient and climatically-adapted tall buildings has been highly influential in architectural design since the 1980s. Some examples are examined below.

The Menara Mesiniaga is the headquarters for IBM near Kuala Lumpur (Fig.3.3). The 16 storey building is built (1989-1992) by Ken Yeang. The tower has three distinct parts: the middle section rises with spiralling open garden terraces on top of a green base. Ventilation is both natural and by air-conditioning, Building Automated System controls energy features including air conditioning. Main concepts for the Menara Mesiniaga: Sky gardens, spiraling vertical landscape, recessed and shaded windows on the east and west, curtain wall glazing on the north and south, naturally ventilated and sunlit toilets, stair ways and lift lobbies, the rain water collection system is also on the roof [3.4].

The 53-storey, 299 meter Commerzbank building, designed by Norman Foster (1994-97), was one of the world's first eco-friendly high-rise towers (Fig.3.4). All offices have natural ventilation and opening windows to reduce energy consumption. Through the center of the building, through each of the building's nine internal gardens (with 4-storey height), outside air is allowed to enter and circulate freely. It has a continuous atrium in its center and natural ventilation shaft brings daylight into the interior offices. The design of the double skin facade is central to the issue of sustainability. These facades allow ventilation for offices with

Fig. 3.5. RWE Headquarters



openable windows. It is a good example of the use of simple passive techniques of renewable energy use and conservation. Building Management System monitors temperature and light sensors, controls the natural-mechanical ventilation and motor-driven sunshadings, system automatically locks the windows depending on the outside weather conditions [3.4-9].

The RWE headquarters in Essen is designed by Ingenhoven Overdiek and Partner in Essen (1997). The 163m tower has a double skin facade. A single layer of strengthened safety glass is used in outside and the inner glazing is heat-insulated glass. The corridor façade is segmented at each floor plate [3.8]. All office windows can be opened for natural ventilation. Around the perimeter of the building the double façade has like-valve horizontal mullions between floors. It allows airflow and temperature control. Aluminum lamellae are controlled electronically and provide protection from the sun [3.4]. Environmental conditions are managed by Building Management Systems technology. An operable window control system allows user localized adjustment by single control panels. Some of the building's energy is generated by PV panels which are located on the roof-level [3.5].

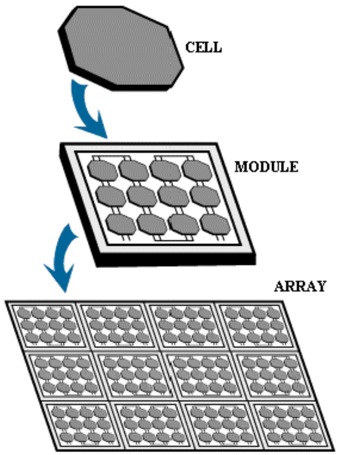
3.3. The Renewable Sources of Energy

To design sustainable buildings, those rely on renewable resources to produce some or all of their own energy and create no pollution, became important design criteria in the last decade. The universal interest compels to rely on the renewable sources of energy because of global warming and other environmental problems caused by current energy sources. Providing renewable energy directly to buildings would reduce their CO_2 emissions. The use of productive mode systems such as PV panels, wind turbines has become more common. Solid waste and wastewater discharge control is also significant in the development of sustainable skyscrapers [3.5].

3.3.1. Solar Energy- Photovoltaics

Solar cell/Photovoltaic (PV) is one of the most promising renewable energy technologies. PV utilizes a renewable energy source and has no emissions; it makes

Fig. 3.6. Photovoltaic cell also called as solar cell and the diagram shows the basic operation



electricity out of sunlight, with no maintenance, no pollution and no depletion of materials. The architectural challenge of solar cells is consistent despite climate differences and different building locations. Photovoltaics can be defined as the direct conversion of light into electricity at the atomic level. Some materials have the ability to absorb photons of light and release electrons; this property is generally defined as the photoelectric effect of a material. Electric current is occurred and can be used as electricity when the free electrons are captured. The space industry used this technology to provide power aboard spacecraft in the 1960s. The technology advanced through various space programs and the cost began to decrease. The recognition of the photovoltaic technology for non-space applications was in the 1970s during the energy crisis [3.10].

Solar cells are composed of semiconducting materials. Silicon is one of the mostly used semi-conducting material. A transparent anti-reflection film protects the cell and decreases reflective loss on the cell surface [3.10]. They become electrically conductive when supplied with light or heat, but they operate as insulators at low temperatures.

Three types of silicon materials are used for the fabrication of solar cells and different types of cells have different properties.

- Monocristalline silicon (m-Si), black or gray color
- Polycristalline silicon (p-Si) are most often bright blue and "shiny" because of the many small crystals
- And amorphous silicon (a-Si) cells are often called as thin-film cells. They are brownish or reddishbrown.

The conversion efficiency of modules of amorphous silicon cells varies from 3 to 8%. Modules of polycrystalline silicon have a conversion efficiency of about 9-12%, while modules of monocristalline silicon cells have an efficiency of 12-16%. [3.11]

<u>Photovoltaic module</u>**:** A photovoltaic module is a number of solar cells that electrically connected to each other and mounted in a support structure or frame. Modules supply direct-current (dc) electricity at a certain voltage. They can be connected in both series and parallel electrical arrangements. The current produced is directly dependent on the amount of light that strikes the module [3.10].

Fig. 3.7. A photovoltaic cell-module-array

Fig. 3.8. A PV skylight entryway

A standard module is a glazed unit of typically 0.5 m2 area comprising of 30 to 40 solar cells connected together to an electric power of 45 to 60 W. The primary energy consumption to produce a complete photovoltaic system is amortised by the energy yield in operation over five (amorphous cells) to seven years (crystalline cells) [3.13]. To form an array multiple modules can be wired together. Photovoltaic modules and arrays can be connected in both series and parallel electrical arrangements to produce any required voltage [3.10]. They have to be mounted on stable, durable structure that can withstand wind, rain, hail, and other adverse conditions [3.12].

PV provides a clean, noise free energy source. The output of the PV module is directly proportional to the amount of sunlight. A complete PV system has three subsystems:

- PV devices (cells, modules, arrays, etc.)
- Load (the application for which the PV electricity is intended)
- Third system generally defined as BOS "balance of system", it consists of structural devices for PV arrays and the power-conditioning equipment. For buildings that are out of reach of the utility grid[36] it can also consists storage devices for storing electricity to be used at nights or cloudy weather conditions [3.12]. In grid-connected applications PV electricity is fed into the utility network by an inverter [3.11].

Interest in the building integration of photovoltaic (BIPV), where the PV elements actually become an integral part of the building, is growing world-wide. Conventional PV systems are either installed on the rooftop of an existing building or placed on freestanding structures. Structural materials are combined with PV material in BIPV technology, to create facades or roofs of a building. They are producing electricity and serving as construction materials. The integration of photovoltaic panels into roof or façade elements is possible because of their modular layout, lightweight and simple assembling [3.11].

[36] Most building integrated PV systems, however, are grid connected because they are located in areas within reach of the utilities. [3.11]

Fig. 3.9. PV Roof Panels

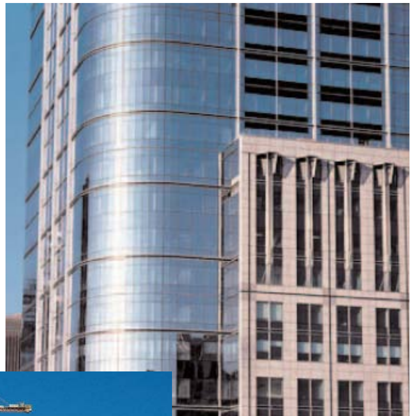


Fig 3.10: The 4 Times Square Building

It is possible to identify three main principles for PV integration into buildings:
1) Weather skin: roof and facade integration
2) Solar shading elements
3) Daylighting elements

With the emergence of photovoltaics architectural skin has a new feature; energy production. PV modules can fulfil various functions in the building envelope. They supply energy and they can also make a positive contribution to the architecture of a building as a building component [3.11]. Photovoltaics can be incorporated into double glazing easily. In combination with coatings, properties such as thermal insulation, solar control, noise protection, etc. can be obtained. Additional electricity can be consumed by computing equipment, communications technology, air-conditioning and artificial lighting [3.13]. The integration of PVs depends totally of the architectural project in which they will be applied [3.14].

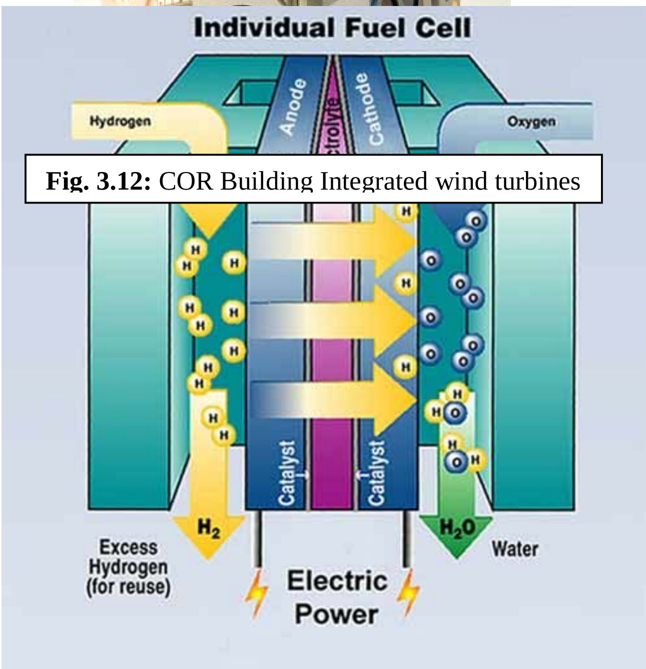
The PV application can be significant for high-rise buildings. Building-integrated photovoltaic (PV) panels supplement The 4 Times Square Building’s (New York) electrical needs. The 48 storey building is designed by Fox and Fowle (1999). It is determined that the optimum area for the PV skin is between the 37th to the 43rd floor. Thin-film PV panels are located on the top 19 floors of the building on the southern and eastern sides.

3.3.2. Wind Energy:

Wind power is the conversion of wind energy into electricity. Wind energy could make a significant contribution to energy requirements in the built environment. Since wind power increases in direct relation to height, tall buildings offer a great opportunity. The number of building integrated turbine installations is not so much but expected to expand rapidly. The Bahrain World Trade Center designed by Atkins Architecture (2007), has three massive wind turbines measuring 29 meter in

Fig. 3.11: Bahrain W.Trade Center

Fig. 3.12: COR Building Integrated wind turbines



diameter (fig. 3.11). They are supported by bridges spanning between two 240-meter high towers. The turbines are expected to generate 11-15% of the buildings' energy needs. The shapes of the towers are designed to funnel wind through the gap to provide the maximum amount of wind passing through the turbines, which confirmed by wind tunnel tests. This significantly increases their potential to generate electricity. Another example of building integrated wind turbines is the COR Building (fig.3.12).

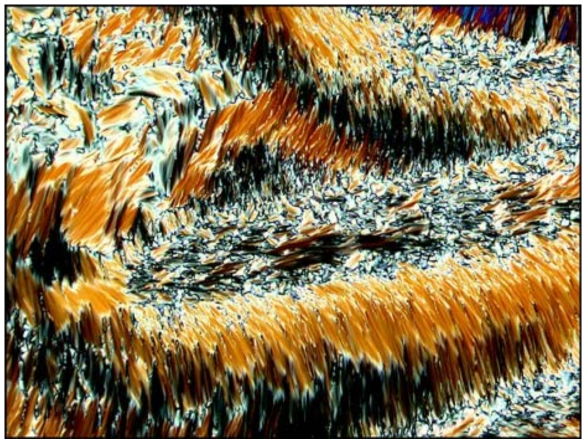
3.3.3. Fuel Cells

The use of Hydrogen Fuel technology is a pollution-free energy source, also promising as a productive mode method [3.4]. Fuel cell technology was first used successfully at the end of the 20th century in space craft to provide electricity and water. Hydrogen fuel cells use hydrogen and oxygen gas to create electrical energy. Fuel is not "burned" like conventional technologies; it is combined in a chemical process. A fuel cell consists of two electrodes sandwiched around an electrolyte. As shown in the figure 3.13, flow plates are used to bring hydrogen gas to one side of the fuel cell while oxygen is brought to the other, generating electricity, water and heat. In principle, a fuel cell can provide electrical energy and heat as long as hydrogen is supplied [3.15]. A catalyst breaks the hydrogen gas into positive ions and electrons. Protons pass through the central membrane at the same time electrons are stuck and flow away through conductors [3.16]. Thus the electric power is provided. Several fuel cells are connected to provide higher voltage and more current. The needed hydrogen for a fuel cell can be supplied from renewable sources such as wind or solar power and oxygen can be supplied from the air, though the infrastructure for renewable hydrogen has yet to be developed. Hydrogen can also be supplied from any hydrocarbon fuel, from natural gas, methanol, and even gasoline. Emissions from this type of system are much smaller than emissions from the cleanest fuel combustion processes. Using of fuel cells for buildings is a developing technology [3.15-4]. Reducing cost and improving durability are significant challenges to their commercialization.

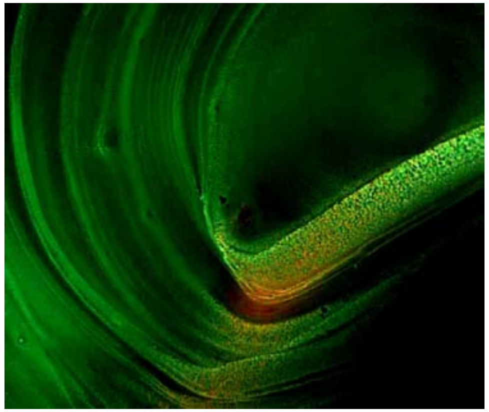
They produce electricity with a very high operating efficiency, and their waste heat can also be used. They are more efficient than co-generation systems in producing electricity, and also they produce fewer emissions, and make less noise. Researchers are working on to develop a second-generation fuel cell system with advanced technology, lower cost, longer life, and greater adaptability to co-generation. Other benefits of the fuel cells are: decrease in CO_2 emissions due to the large fall in primary energy consumption and decrease in the need for an electric utility infrastructure. It provides also cost reductions in the delivery of electric services [3.4].

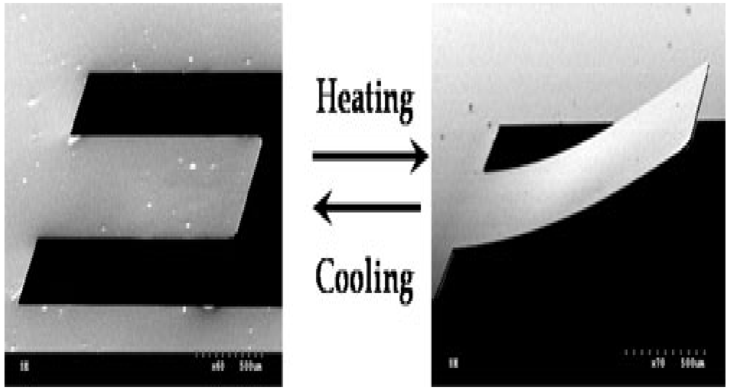
Fig. 3.13. Fuel Cell

Energy conscious design is one of the responsibilities of the architects requiring an understanding of the fundamental materials and devices. The true material selection plays a key role. To produce energy from the above mentioned renewable sources smart materials offer beneficiary solutions. As seen from the examples, for designing and building a sustainable future the impact of these materials are significant. The main objectives of smart materials are to prevent resource depletion of energy, water, raw materials and create built environments that are safe, and productive. The detailed analyses of the smart materials are examined in next chapter.



PART 4. SMART MATERIALS





PART 4. SMART MATERIALS

Smart materials can be generally defined as the engineered materials that perform special tasks. These are the materials which have one or more properties that can be altered by external stimuli like temperature, moisture, electric field etc. NASA's definition of smart materials is 'materials that remember configurations and can conform to them when given a specific stimulus' [4.2]. As a naturally occurring smart material, skin is a good example. It senses the sunlight, changes pigmentation in response, and the colour signals that tanning or burning is occurring [4.1]. Advances in smart materials are impacting various disciplines.

Basic types of smart materials are normally used in conjunction with many other materials. With the conjunction of other materials; devices, components, assemblies and systems can be produced. Complex functions are needed for using these materials in design context and single materials cannot alone respond many demands. External walls in a building, for ex., provide a range of functions (thermal barrier, weather enclosure, ventilation, etc.) as well as establishing the visual experience of a building [4.2]. Smart materials can be classified into two types.

4.1 Type I Materials

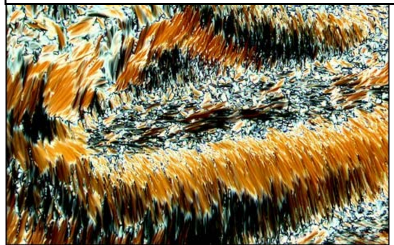
These types of materials change their properties in direct response to a change in the external stimuli which occurred in the material's environment. These changeable properties of the materials can be chemical, mechanical, electrical, magnetic or thermal. Changes occur directly and they are reversible. There is no need for an external control system to cause these changes to occur.

Thermochromic materials change reversibly color with changes in temperature. An input of thermal energy to the material alters its molecular structure and changes its color. The new molecular structure has a different spectral reflectivity than does the original structure. A thermochromic material could be used as a device for sensing a change in the temperature of an environment via its color response capabilities[4.2].

A thermochromic furniture is designed by Juergen Mayer (in fig. 4.1). The furniture changes its color due to the heat released by its user.

Fig.4.1. Thermochromic furniture designed by Juergen Mayer

Fig.4.2. Magnetorheological material



Magnetorheological –the application of a magnetic field causes a change in micro-structural orientation. It results a change in viscosity of the fluid. Figure 4.2 shows A ferrofluid forms spikes along the magnetic field lines when the magnetic surface force exceeds the stabilizing effects of fluid weight and surface tension [4.2].

Fig.4.3. Thermotropic liquid crystal compound

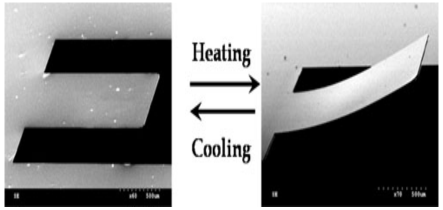


Fig.4.4. TiNi cantilever showing the actuation during heating and cooling

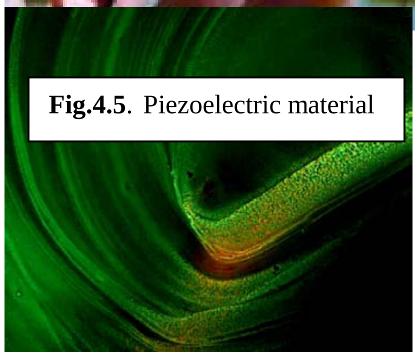


Fig.4.5. Piezoelectric material

Thermotropic – an input of thermal energy to the material alters its micro-structure through a phase change. In different phases, most materials demonstrate other properties, including conductivity, transmissivity, volumetric expansion, and solubility [4.2].

Shape Memory - an input of thermal energy alters the microstructure through a crystalline phase change. This change enables multiple shapes in relationship to the environmental stimulus [4.2].

4.2. Type II Materials

These types of materials transform energy from one form to output energy in another form. They have the ability to do this again and again directly and reversibly. Therefore, an electro-restrictive material transforms electrical energy into electric (mechanical) energy [4.2]. This process results with a physical shape change. These materials are constituted in a way to provide a particular type of function. In the use of type 2 materials as a sensor or actuator, there are also different kinds of electronic systems that are integral to the system to amplify, modify, transmit, or interpret generated signals. Examples include photovoltaic which is mentioned in Part 3 and some others are;

Piezoelectric – these materials produce electrical charge when mechanically stressed. Most piezoelectrics are bi-directional in that the inputs can be switched and an applied electrical current will produce a deformation (strain) [4.2]. Figure

4.5 is the piezoelectric material, developed at NASA's Langley Research Center (LaRC), can "feel" deformations such as bending or surface pressure, producing a small voltage in response that can act as a signal for a central computer [4.3]. Piezoelectric crystals could be used as actuators by passing an electric current through the material to create a force [4.2].

Photoluminescent – an input of radiation energy from the ultraviolet spectrum is converted to an output of radiation energy in the visible spectrum.

Fig.4.6. Photoluminescent crystals

4.3. Sensors

Many smart materials also act as sensors or actuators. As sensors, a smart material responds to a change in its environment by generating a perceptible response. Many common sensors and actuators are based on the use of smart materials [4.2].

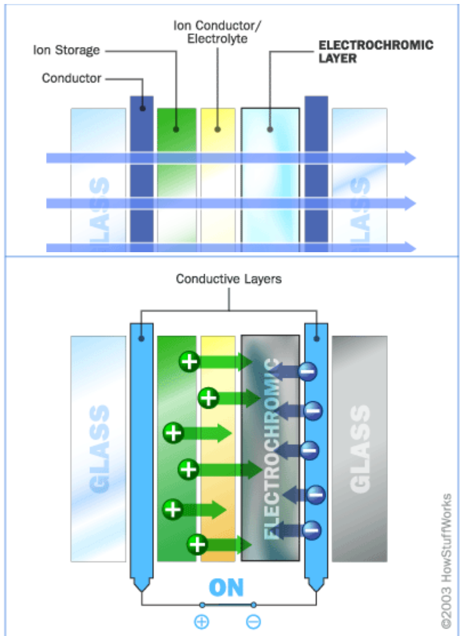
Sensors can model physical, chemical and biochemical parameters. They are detection devices that respond to different types of stimuli by returning a differential voltage output. Many types of sensors are commercially available; they are built into many consumer electronic devices, security and safety devices, and systems for monitoring pollution and environmental conditions. Sensor/computer/actuator technologies are used in buildings for several decades, such as the elevator and the thermostat [4.4]. With the new technological developments sensors become a significant part of architecture. They work like a nerve system for a building. They can feel and determine the reaction to internal and external conditions. All type of data and information to systems are achieved through the sensors [4.5].Their potential to create new ways of interaction between people and architectural space is starting to be explored. Sensors generally work in connection with a microcomputer that averages, calibrates, and processes the input of a potentially large number of sensors [4.6].

Sensors are classified into three groups: Security and Safety Sensors, Weather and Space Quality Sensors, System Monitoring Sensors

Security and Safety Sensors: Security, safety and surveillance sensors serve interior and exterior environment. Fire and smoke detection, photo optics, access, acceleration and vibration, motion and human presence

Weather and Space Quality Sensors: Temperature, humidity, solar radiation, pressure, light, flow (liquid and gas), air contents, moisture, chemical measurement [4.5].

System Monitoring Sensors: Structural system monitoring, Mechanical system monitoring (like HVAC system), all other systems that require monitoring detection solar radiation, security, noise pollution, and façade optics and colour change, are some of exterior sensors controlled systems. Systems like energy, air control, lighting system, and air-condition controlling use interior sensors to reach intelligent architectural solutions [4.5].



4.4. Electrochromic Smart Windows and Dynamic Process:

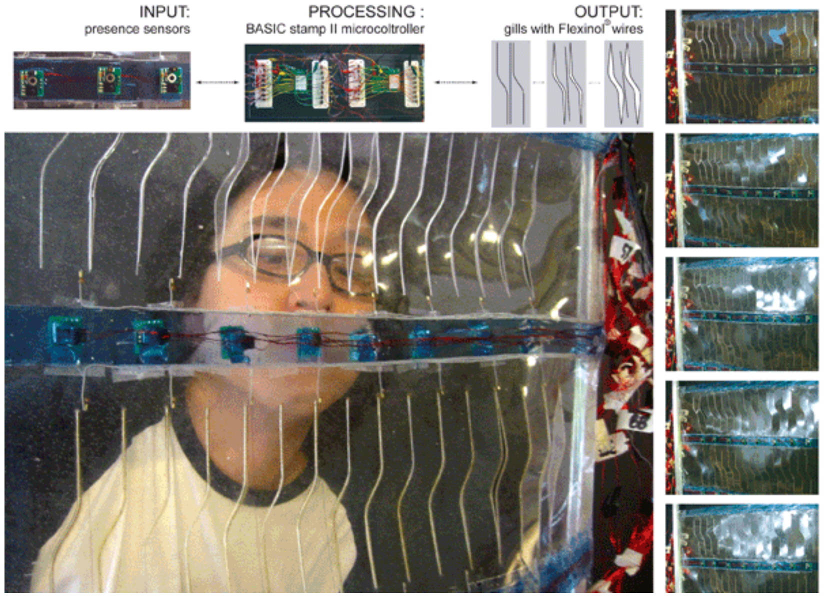
Smart windows have the ability to change their optical properties in a reversible manner when voltage is applied and current flows through them. They need thermochromic or electrochromic properties to achieve this goal. Most of the smart windows rely on a thin layer of electrochromic coating, generally composed of the oxides of certain metals [4.6]. These electrochromic coatings are one of the most important of the new generation advanced glazing materials. By employing electrochromic glazings in a curtainwall or window system daylight levels can be altered dynamically. Thermal energy flow can also be controlled in the entire building envelope [4.7].

The change of opacity is given by applying a low-voltage electrical charge. This reverses the shuttling of charge ions between the electrochromic thin film and a transparent conductor. Glass darkening reduces solar transmission into the building. The electric current can be activated manually or by sensors which react to light intensity [4.8]. Electrochromic glass is an energy-saving component, studies show that by adopting “smart window” energy control strategies in a building 170 kWh/m2 in energy can be saved annually [4.6]. Although these glazings are not yet commercially available, significant progress is being made in R&D labs to estimate their energy-saving potentials for commercial building applications.

Fig.4.7. Electrochromic Smart Window

Dynamic Process: The optical and thermal properties of the reactive environmental facade can be dynamically changed in response to climate or occupant preferences. Like the reactive environmental facades data driven screens also involve the design of dynamic process. The reflection of today’s dynamic, flexible and constantly changing activities becomes an important design criterion. Technological developments encouraged architects to think of building’s facades as dynamic systems.

With smart materials, electronic computer systems, and other technologies, architecture is increasingly described as dynamic, responsive or interactive. Intelligent construction materials have the potential to incorporate display and data components. Developments in display technology and building materials led to new forms of hybrid architecture. Light Emitting Diode (LED) displays integrated with the fabric of built structures allow prominent imageries. Real and virtual architecture come together in this hybrid architecture. Between the computer’s abilities and the physical world, integration is occurred. It gives the systems the ability to communicate and transfer information. Facades that interact with surrounding environment and its inhabitants have a great visual impact in urban environment. In this context tall buildings have particularly significant. Research projects and some buildings that employ the above mentioned systems are presented below.



Living Glass: The project of David Benjamin and Soo-In Yang, is emerged through the idea that architectural elements might move in response to the environment. The "Living Glass" project uses a shape memory alloy to open and close the polymer surface like gills on fish. To achieve this, they embedded Dynalloy Flexinol wires in cast silicone surface. The thin shape memory wires contract when current passes through them, causing gills to cut into the surface to open and close. The carbon dioxide sensors regulate air quality in the room when carbon dioxide levels are high. The movement allow air flow when needed, and it provides information by signalling a high carbon dioxide level [4.9].

Fig.4.8. Living Glass Project

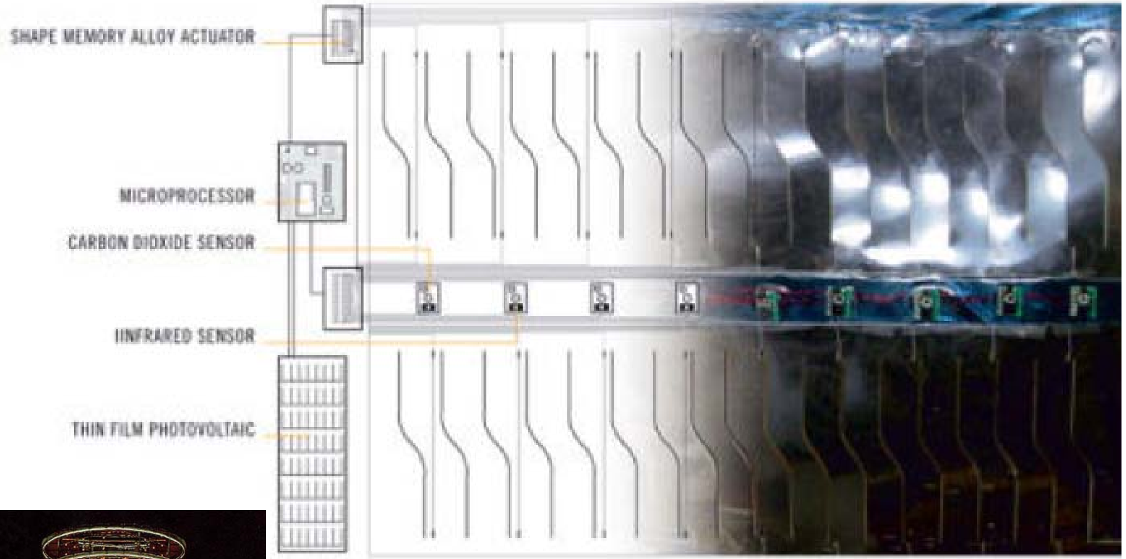


Fig.4.9. Sensor and actuator technology in Living Glass Project



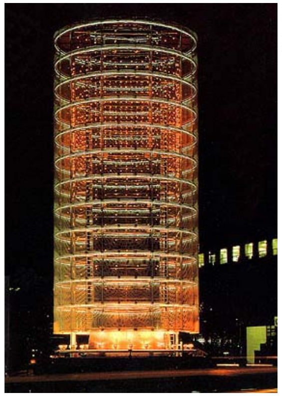



Fig.4.10. Tower of Winds- In the daytime, the Tower looks like an opaque object suspended in the sky.

<u>Tower of Winds</u>: Tower of Winds was realised by the architect Toyo Ito in 1986 near the central railway station in Yokohama, Japan. He fused hi-tech media with nature's basic elements such as light, wind and sound. The cylinder shaped tower is 21 m high and it was made as a ventilation and water tank facility for an underground shopping center. The concrete structure is covered with aluminium panels. The tower, covered in acrylic mirrors with 1280 LEDs and twelve neon rings. The lights are computer-programmed to generate different patterns based on information gathered from the surroundings. The colors of the mini lamps change in reaction to the noise around the Tower and the aluminum panels appear and disappear with the wind. It has also thirty floodlights at the base. Inside, another light system creates different light effect depending on the hours and some environment parameters. Light of reflectors changes intensity and luminous flux depending on the wind's direction and speed [4.10-11].

Agbar Tower: 142 m Agbar Tower is designed by Jean Nouvel in Barcelona (2005). The nocturnal illumination gives a unique feature to the building. A total of 4,500 L3 RGB lights were installed to illuminate the 32 floors of offices in the tower. The lighting system, which has 4,500 L3 RGB lights, is controlled from a single computer. It is made up of 4,400 windows and 56,619 transparent glass plates and translucent ones. Aluminium panels in 25 different colors located behind glass louvers. The louvres are titled at 14 different angles calculated to deflect direct sun light [4.12]. Temperature sensors regulate the opening and closing of the glass blinds of the facade, optimizing the consumption of necessary energy to the air conditioning.

Fig.4.11. Agbar Tower

Zeilgallery: Reactive facade at the Zeilgallery in Frankfurt, is designed by Christian Moeller and Ruediger Kramm in1992. This light-sculpture like facade is mounted on the front of the “Zeilgalerie” department store. Behind a screen of perforated aluminium, 120 floodlights fade from blue to yellow. They illuminate the front of the building, beam upwards and downwards through the surface with a varying degree of yellow.

The appearance of the facade is directed by a weather station and a computer (Silicon Graphics Indigo Entry) on the top of the building: the ambient temperature (variables: 0°-30° C) determines the amount of yellow on the blue wall. Temperature, wind, and rain define the amount of yellow in the piece. The yellow patches move in line with the direction of the wind. Wind speed governs how fast they move over the surface while rain determines their vertical flow. The upper part of the facade is crossed horizontally by the wide, rapidly changing line graphic (LED-Display 4m x 20m). At night it visualizes the level of noise of passers-by in real-time. During the day this graphic display is used for the presentation of the local news [4.11-13-14].

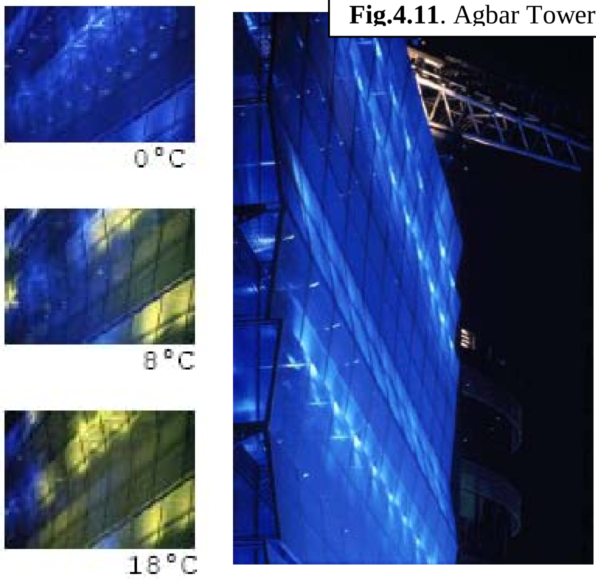


Fig.4.12. Reactive facade at the Zeilgallery

Fig.4.13. 120 flood lights blue to yellow

Dexia Tower: 145 metres Dexia Tower designed by M. & J-M. Jaspers - J. Eyers & Partners (2006). With 38 floors it contains 4200 windows. These are each fitted with individually controlled RGB LED bars, turning the façade into a huge screen. Instead of a flat screen displaying pre-rendered video loops, the project utilized the architectural characteristics of the tower and its urban context. The main thrust of the project was to allow people to directly interact with the tower. Over the New Year period visitors were able to define colors and patterns displayed by LED lighting fixtures. This was transformed the Dexia Tower into a giant interactive LED display.

At the bottom of the tower, a station was mounted where people could interact with the visual and luminous display through a multi touch screen. The "Touch" project was developed by LAb[au]. Static and dynamic input, based on parameters such as width (e.g. of a finger or hand), direction, duration and speed were accepted by the touch screen. Every single LED fixture is controlled independently, by a wiring system and ethernet cables and the creation of software has been installed in a large

Fig.4.14. Dexia Tower

Fig.4.15. Touch Screen at the bottom of the Dexia Tower

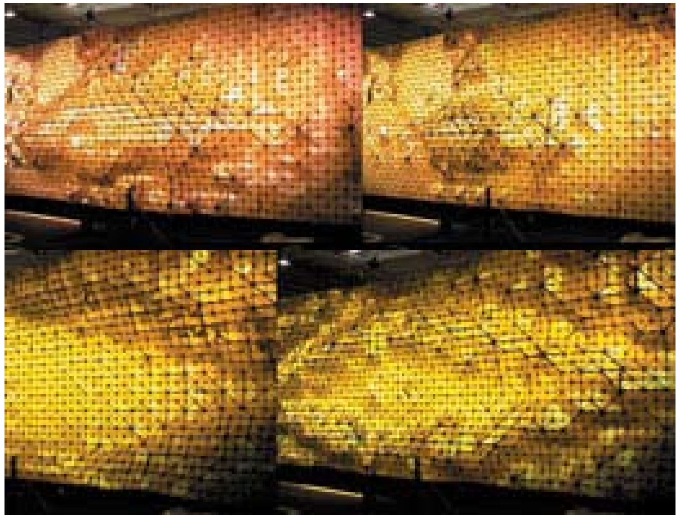


Fig.4.16.The Aegis Hyposurface

central computer. This can control each floor individually and combine all the shows [4.16].

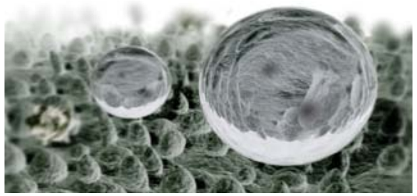
Once a composition was created on the giant LED display, a snapshot of the tower was taken from a distant location. The image could be sent as an electronic postcard, and was also uploaded onto the project website. [4.15, 4.16]

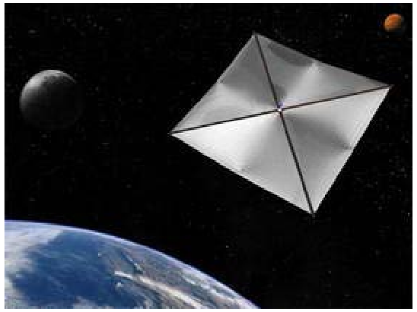
<u>The Aegis Hyposurface</u>: The Aegis Hyposurface was developed for a competition for an interactive art-work for the foyer of The Birmingham Hippodrome Theatre in 2001. It is designed principally by Mark Goulthorpe and the dECOi office with a multi-disciplinary team (architects, engineers, mathematicians and computer programmers). The project continues to be under research at MIT's Media Lab.

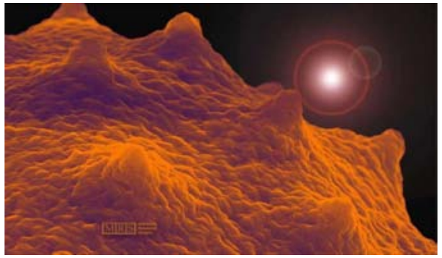
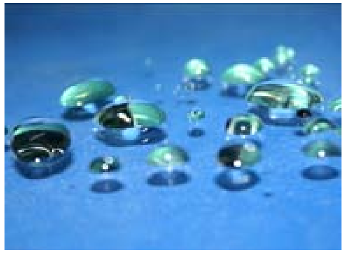
The Aegis project consists of an interactive mechanical surface. It has potential to deform physically in response to electronic stimuli from the environment. The changes in the stimuli are captured by the sensors. The surface reacts in real time to the sounds and movements of people, weather, and electronic information by transforming topography and colors. The elastic surface is driven by a bed of pneumatic pistons, which offer a displacement performance. This project foreshadows kinetic and environmentally responsive architectural surfaces. Goulthorpe defined the project as a transition from autoplastic (determinate) to alloplastic (interactive, indeterminate) space [4.17].

Fig.4.17. The changes in the stimuli are captured by the sensors.

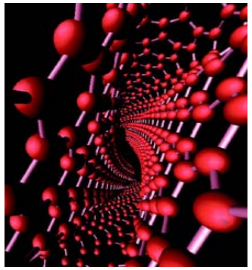
Smart materials offer different and significant solutions for various architectural demands. Their potential is already recognized by the architects and they will be inevitable elements for the future projects with enhanced properties. In the near future, nanotechnology has the potential to offer architecture an abundance of smart materials that will be precisely engineered to perform specific tasks. The details of the Nanotechnology which is considered as the technology of the future are discussed in the next two chapters.





PART 5.



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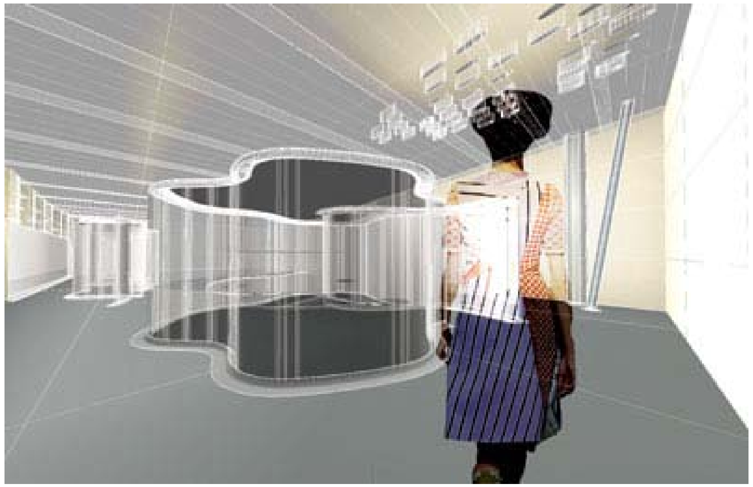
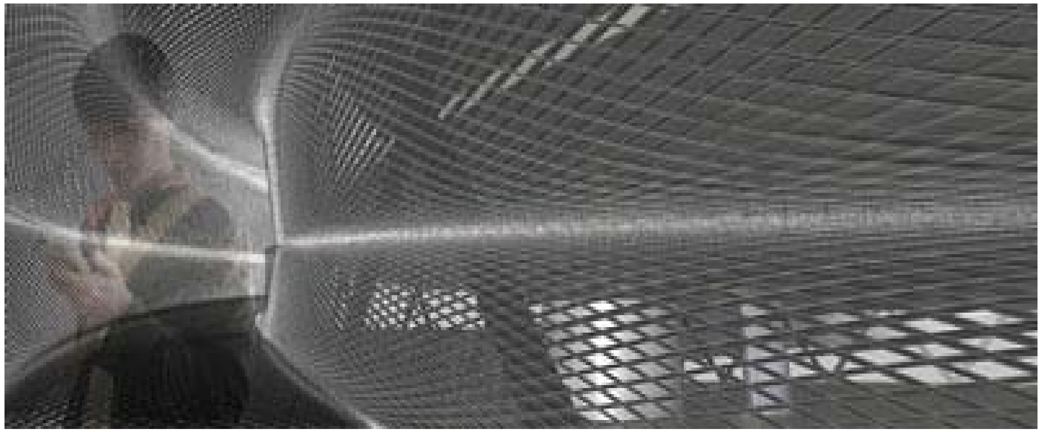

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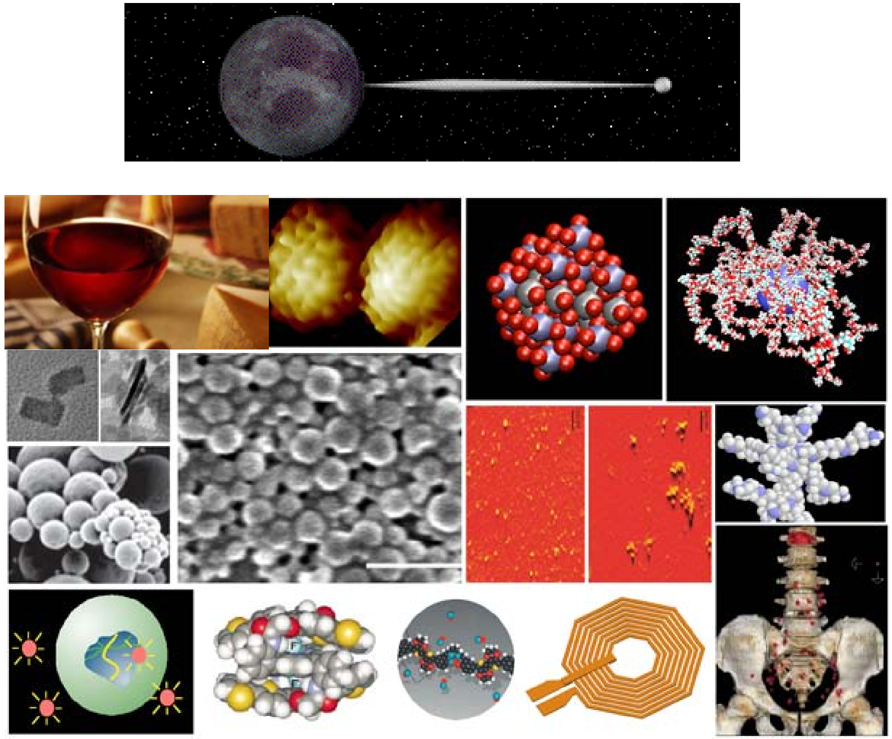

Fig. 5.1: Nanotechnology

5.1. Introduction

Nanotechnology offers the possibility of significant advances over conventional technologies. This technology will change the rules of architectural design practice and, civil, structural, environmental, electrical and mechanical engineering, as well as other professions to break away from their traditional design parameters [5.1]. It is believed that nanotechnology has the potential to be the Industrial Revolution of the 21st. This technology promises to recreate our seen world from the bottom up, and to create new worlds of the unseen. It breaks the relationship between visible and invisible.

Nanotechnology is the ability to manipulate matter at the molecular scale for creating something new. The atom manipulation has been done for centuries by casting, milling, grinding, and chipping. Making stone tools and flint knives rely on arranging atoms, and arranging the atoms in coal yields diamonds. This manipulation type involved large groups of atoms but nanotechnology manipulates much smaller bits. With this technology it is possible to make products that are lighter, stronger, smarter, cheaper, cleaner, and more exact. By manipulating the way atoms behave to create lighter materials, for example, a car could weigh 50 kilograms [5.2].

Research on nanotechnology is key factor for the development of high-tech materials. It is already employed in the manufacture of everyday items. Nanotechnology has the potential to transform the built environment radically with the developments of these new materials. Its introduction to architecture is take place with the building enclosure materials like coatings, panels and insulation. Even these first steps could dramatically alter the nature of building enclosure. With these completely new materials and components more durable, efficient, cost-effective and superior buildings can be realized. They have lighter, stronger and fatigue resistant materials that perform better and last longer [5.1]. It can bring dramatic improvements in building performance; energy efficiency and sustainability.

5.2. Definition

Scientists and engineers have the ability to create new materials with fundamentally new and beneficial technologies. The development and use of nanotechnology and biotechnology offer new solutions [5.3].

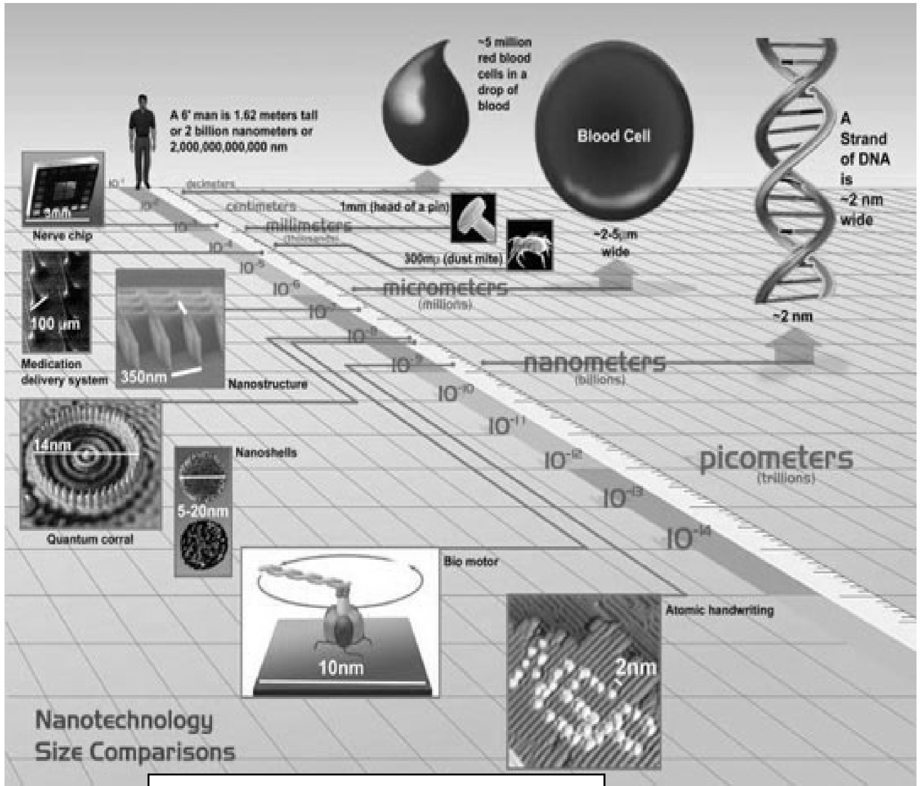

Fig. 5.2: Scale of Nanotechnology

Nanotechnology is a relatively new field and is predicted to be one of the key technologies of the 21st century. It is a multidisciplinary field that includes materials science and engineering, mathematics, physics, biology, chemistry, computer science, and many other scientific areas. Therefore, it has attracted the attention of researchers, from physics to chemistry to biology and engineering.

The prefix "nano" derives from the Greek word “nanos” for dwarf and expresses extreme smallness. In English nano refers to one-billionth represents one-billionth of a unit. For example, nanometer shows the length that is measured in billionths of a meter [5.4].

The figure 5.2 helps us to understand this size and to show how small nano really is: Nanotechnology, in general, may be described as the engineering of materials and structures at a nanoscale. In a broad manner, nanotechnology is the study, design, creation, characterisation, manipulation, and application of functional materials, devices, and systems through control of matter with a dimension or production tolerance of less than 100 nanometres [5.5]. The reason for the widespread interest in this field is the ability to manipulate individual atoms and molecules to produce nano-structured materials. Once it becomes possible to control feature size, it will also become possible to enhance material properties and device functions. The properties of these materials actually become affected and they behave differently from the same materials produced on a larger scale. They exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes because of their nanoscale size. New and smart materials can bring many significant advances and can be applied in various areas such as components used for batteries, sensors, packaging materials, pigments and artificial body parts. Construction industry also benefits from those materials for buildings, roads and bridges, through retrofitting and repair technologies to fire prevention.

Fig. 5.3: Galatée aux Sphères (Salvador Dali, 1952) Dali was impressed by human progress in mastering matter at smaller dimensions. He decomposed the spirit of his beloved muse, Gala, in atomic spheres.

Fig. 5.4: A XVI century dish from Deruta, with gold lustre decorations.
Museo Regionale della Ceramica, Deruta, Italy

5.3. History & Development

The following quote, attributed to Thomas Edison, originally appeared in an 1890 article by George Lathrop in Harper's Magazine (issue 80), and is recounted in Paul Israel's 1998 biography of Edison:
"... as if out of a great revery, saying what a great thing it would be if a man could have all the component atoms of himself under complete control, detachable and adjustable at will. "For instance," he explained, "*then I could say to one particular atom in me – call it atom No. 4320 – 'Go and be part of a rose for a while.' All the atoms could be sent off to become parts of different minerals, plants, and other substances. Then, if by just pressing a little button they could be called back together again, they would bring back their experiences while they were parts of those different substances, and I should have the benefit of the knowledge*"[5.6].

Although nanotechnology first captured the world's attention in the second half of the twentieth century, nanomaterials have been around for centuries. Renaissance artists used paints and glazes with unique properties of color and brilliance that were caused by nanoparticles. The first examples dated from the IX century AD in Mesopotamia. Potteries had gold and copper-coloured metallic reflections and iridescence in the Middle Ages and Renaissance Era. These are called lustre and originate from a metallic film that was applied to the transparent surface of medieval glazed pottery. This technique displays that craftsmen had a technological and empirical knowledge of materials science and were ahead of their times. Because of the high quality of the film and its resistance to atmospheric oxidation and burial weathering the lustre is still visible after centuries. The composition of the film creates the peculiar optical effects, with silver and copper nanoparticles. They dispersed homogenously in the glassy matrix of the ceramic glaze. Artisans put a mixture of copper and silver salts and oxides, together with vinegar, ochre, and clay, on the surface of previously-glazed pottery to create these nanoparticles . The object was then placed in a kiln where it would have been heated to about 600°C in a reducing atmosphere. The high temperature caused the glaze to soften, and then the copper and silver ions would have migrated into the outer layers of the

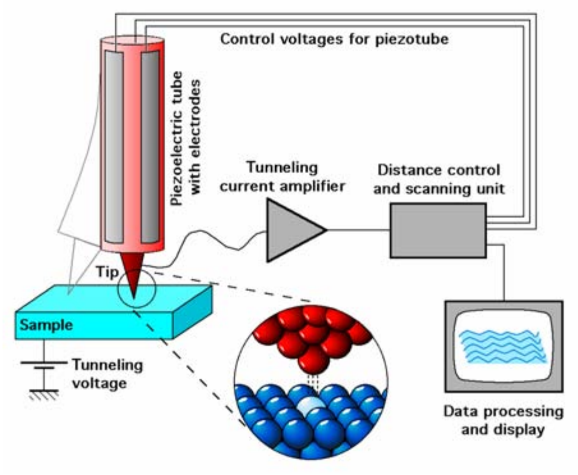

Fig. 5.5: Schematic view of an STM

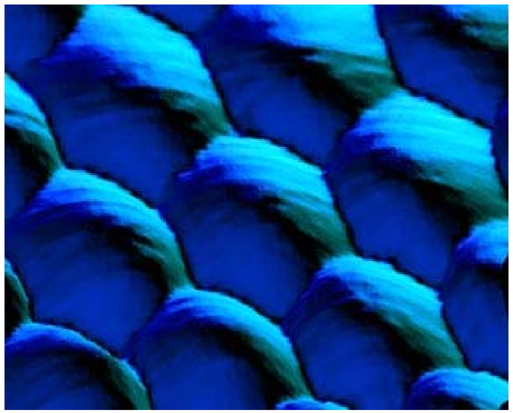

Fig. 5.6: Blue Platinum. The surface of Platinum image by a STM

glaze. The reducing atmosphere reduced ions to metals, which then came together forming the nanoparticles that give the colour and optical effects [5.7].

For the last century; carbon black has been used in automobile tires to reinforce the rubber material. Vaccines also consist of one or more proteins with nanoscale dimensions [5.8]. Generally scientific discussion about the nanoscale was initiated in 1959 when Nobel Prize winner Richard Feynman delivered his famous speech "There's Plenty of Room at the Bottom." Feynman proposed that the properties of materials and devices at the nanometer range would present future opportunities [5.9]. He did not bring up the term nanotechnology[37] at that time but he showed the possibilities of a new type of science at the atomic scale [5.8]. He had also pointed out that a new class of instruments would be needed to manipulate and measure the properties of the small "nano" structures. These instruments were invented in the 1980's [5.8]. The development of the scanning tunnel microscope (STM)[38] in 1981 represented a milestone in the evolution of nanotechnology. STM provided the first direct access to the atomic world. STM, atomic force microscope (AFM)[39] and the near-field microscopes are indispensable for nanostructure measurement and manipulation.

[37]The term 'Nanotechnology' was introduced by N. Taniguchi in 1974 to describe the precision manufacture of materials with nanometer tolerances [5.10].

[38] STM is a type of electron microscope that shows three-dimensional images of a sample. It enables to study the structure of a surface by using a stylus. It scans the surface at a fixed distance [5.11]. It becomes possible to perform structural and spectroscopic imaging of atoms, molecules and surfaces on a scale down to atomic dimensions, i.e. it allows one to see single atoms on a surface with a resolution corresponding to about 0.1 nm.

[39] AFM, called as the scanning force microscope, is a technology capable of attaining high resolution under physiologically relevant conditions by feeling a sample's surface with a sharp probe [5.12]. It enables to image the atomic-scale properties of non-conductive surfaces either in vacuum or in any medium.

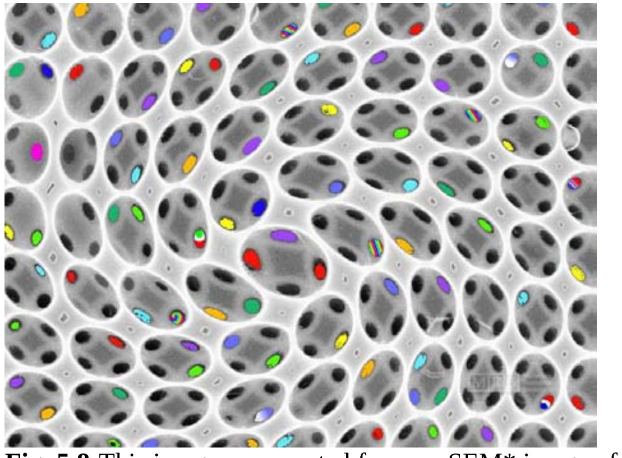

Fig. 5.8: This image was created from an SEM* image of a (100) oriented titania inverse opal. It was formed by low temperature atomic layer deposition of titania within the void spaces of a polystyrene opal with a sphere diameter of 330 nm. The SEM image was acquired at 15kV at 50,000x magnification and subsequently processed with image manipulation software.
Credit: Elton Graugnard, Georgia Institute of Technology

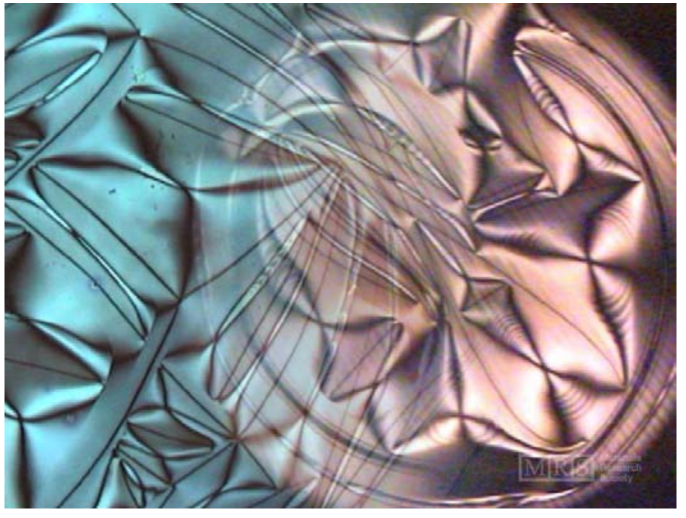

Fig.5.7: Optical microscope image using crossed polarizers of an oriented polymer semiconductor, regioregular poly(3-hexylthiophene), film commonly used in organic field-effect transistors. Two images with magnification 5x are combined.
Credit*:* Tomas G. Bäcklund, Åbo Akademi University, Turku, Finland

Fig.5.9. Highly tapered germanium nanowire grown from a surface imperfection, utilizing the vapor-liquid-solid mechanism on an Si (111) substrate. Imaged via field emission SEM at a magnification of 15k, accelerating voltage of 5 kV, and imaged in plan view, normal to the (111) substrate surface.Credit: Teresa Clement, Arizona State University

* Micro or nanosculptures created through chemical or/and physical processes and then they are visualized with STMs or AFMs. The monochromatic electron microscope scans are processed further using different artistic techniques to create pieces of art. High resolution (SEM) scanning electron micrograph images from the "Science as Art" competitions of MRS (The Materials Research Society) [5.13].

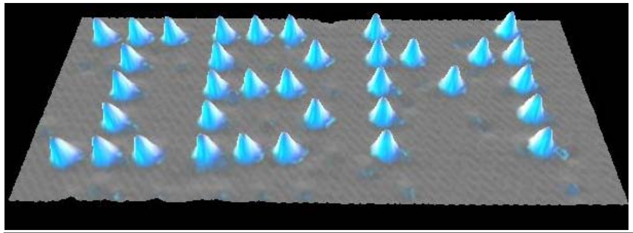
Fig 5.10: Logo of IBM with 35 individual Xenon atoms

Another nanotechnology breakthrough occurred in 1985 with the discovery of fullerenes. The most popular types of fullerenes are Buckyballs and carbon nanotubes (cylindrical fullerenes).
The term nanotechnology reached greater public awareness in 1986 with the publication of “Engines of Creation: The Coming Era of Nanotechnology” by E. Drexler. Dramatic benefits for design, manufacturing, electronics, medicine, and every other human endeavour were mentioned in his book [5.14].
In 1989 the first time ever an atom manipulation has been done. Two scientists from IBM, Eigler and Schweizer, were able to shape the three letters[40] of “IBM” by using 35 individual Xenon atoms and a STM (see Fig. 5.10) [5.15].
The important milestones that have occurred in nanotechnology listed below as a time line[5.16-17]:

1959- Feynman’s talk describing molecular machines building with atomic precision
1974- N. Taniguchi invented the term 'nanotechnology'
1977- Drexler originates molecular nanotechnology concepts at MIT
1981- STM invented by Binnig and Rohrer
1985- Buckyball discovered
1986- E. Drexler published 'Engines of Creation: The Coming Era of Nanotechnology'
1986- AFM invented.
1987- First protein engineered.
1989- IBM uses STM to write IBM with 35 Xenon Atoms.
1991- S. Iijima discovered carbon nanotubes
1993- Nanotubes synthesized.
1995- Complex structures built from DNA
1996- Quantum Wire created by James Tour
1997- First company : Zyvex, Company dedicated to the manip. and formation of atoms
1998- First DNA-based nanomechanical device
2000- US President Clinton announces U.S. National Nanotechnology Initiative
2002- First nanotech industry conference
2004- First policy conference on advanced nanotech
2005- Beam of electrons used to shape metallic nanowires
2006- Technology for making thin film nanotubes by evaporation invented

[40] The logo is 60 billionths of an inch wide, or 13 millionths of the diameter of a human hair [5.18]

5.4. Nanomaterials

Materials science and technology is one of the main areas among the applications of nanotechnology. Controlling the structures of materials at smaller scales is a key factor in the development of new and improved materials. It played a crucial role throughout history, from the steels of the 19th century to the advanced materials of today. Therefore, the understanding of materials and controlling their structure at the nanoscale will provide a great potential to create a range of materials with novel characteristics, functions and applications [5.19].

Nanomaterials can be simply defined as “Novel materials whose molecular structure has been engineered at the nanometre scale.” [5.20]. As mentioned before, nanostructured materials behave very differently compared to conventional materials. They differ from larger materials not only in size, but also in surface/interface-to-volume ratio and grain shapes [5.21]. Their properties are different from other materials because of two principal factors: these are increased relative surface area, and quantum effects [5.19]. These factors can change or enhance the rates and control of chemical reactions, electrical and thermal conductivity, magnetic properties, thermal conductivity, and strength and fire safety. Nanostructured materials can be highly conductive, highly insulating, or semiconducting and can have resistance to fracture or deformation. [5.9]

If the particle gets smaller then it has larger active surfaces per unit mass and greater chemical activity. It means that a given mass of material in the form of nanoparticles is more reactive than the same mass of material made up of larger particles. As the size of the particle decreases more proportion of atoms are found at the surface compared to those inside. For example, a particle with a size of 30 nm has 5% of its atoms on its surface, at 10 nm 20% of its atoms, and at 3 nm 50% of its atoms [5.19].

To consider a material as a nanoscale material at least one dimension shall be 100 nanometres or less. Nanomaterials can be nanoscale in one dimension, two dimensions, or three dimensions. They can exist in various forms: single, fused, aggregated or agglomerated with spherical, tubular, and irregular shapes [5.22]. Common types of nanomaterials are shown below: [5.23].

Classification	Examples
Dimension	
• 3 dimensions<100nm	Particles, quantum dots, buckyballs, etc
• 2 dimensions<100nm	Tubes
• 1 dimensions<100nm	Films, coatings, etc

5.4.1. Nanoscale in One Dimension

5.4.1.1. Thin film & Coatings

One-dimensional nanomaterials, such as thin films and coatings, are material structures that are formed by the deposition of one or more layers of material onto a surface. They have the potential for significant advances in engineering properties. Those advances can be provided by reducing microstructural features by factors of 100 to 1000 times compared to current engineering materials.

The thickness of thin films or monolayers usually ranges from 1nm to 5nm. However, in some cases they can be only one molecule or even one atom thick [5.24]. The area of thin films and coatings had improved over the past decades and they are used in fields such as electronic device manufacture, chemistry and engineering. They have a wide range of properties, from being chemically active to being wear resistant.

The essential benefit of thin films is that the properties of the materials deposited can be acquired by the surface. The thin film and the substrate become a material system where each of them provides the required functionality [5.20]. Coatings are another area of study for nanotechnology and are being strongly influenced by the current developments in this technology. It enables advanced coatings through conventional methods and materials.

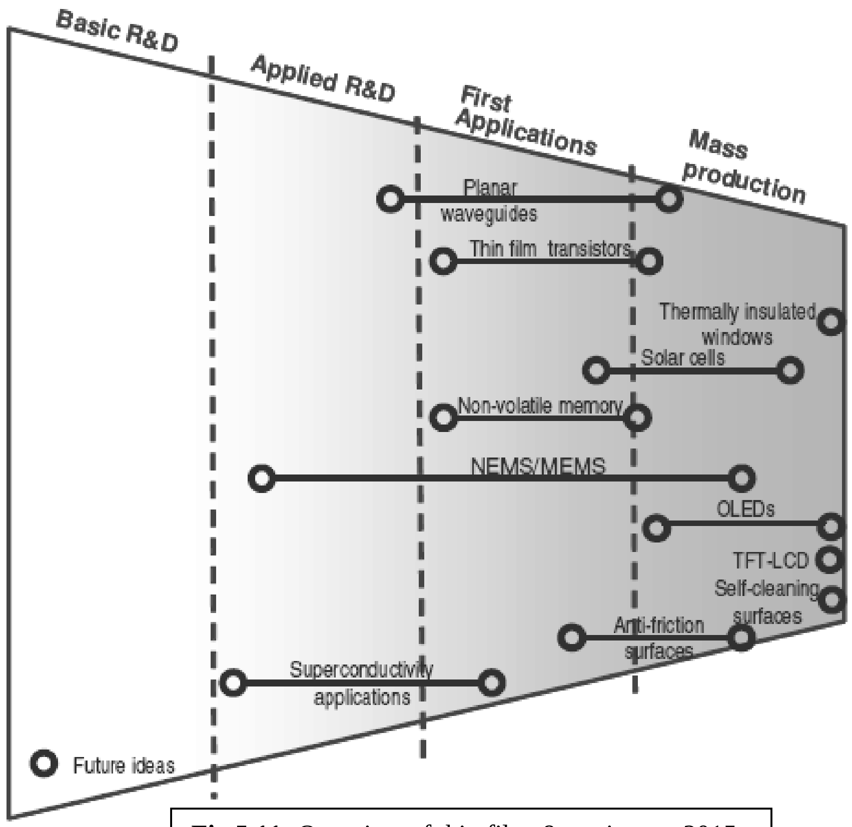

Fig.5.11: Overview of thin films&coatings at 2015

These improved materials and products often open completely new areas of application with an impact in almost every industrial sector such as architecture and construction, textiles, heat exchangers, air conditioning circuits, hygiene-health (hospitals, schools) and food processing [5.25]. This trend plays a significant role also in the glass industry. Many of the possible applications of thin films & coatings can be seen in Fig. 5.11.

5.4.2. Nanoscale in Two Dimensions

5.4.2.1. Carbon Nanotubes

One of the most important materials that nanotechnology investigates is carbon nanotubes. They are a form of carbon and the discovery of them in 1991 by S. Iijima opened up a new era in materials science. CNTs are a true example of nanotechnology; with only a few nanometres in diameter and several micrometres (10-6m) to centimetres long, the length-to-width aspect ratio is extremely high. Carbon nanotubes can be visualized as a modified form of graphite[41]. They are extended tube structures of a sheet or sheets of graphite that have been rolled into a cylinder with a diameter of about one nanometre (see Fig.5.12). [5.26].

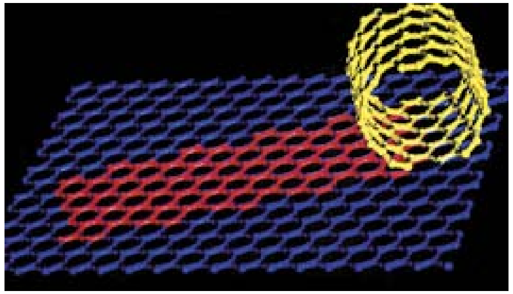

Fig. 5.12: Schematic representation of rolling graphite to create a CNT. Depending on their "rolling" angle, nanotubes with different spirals have different electronic properties.

Typically, there are two types of CNT. These are single-walled nanotubes(SWNT), as if a single sheet had been rolled up or multi-walled(MWNT), similar in appearance to a number of sheets rolled together. Figures 5.13a and 5.13b show schematic of carbon nanotubes.

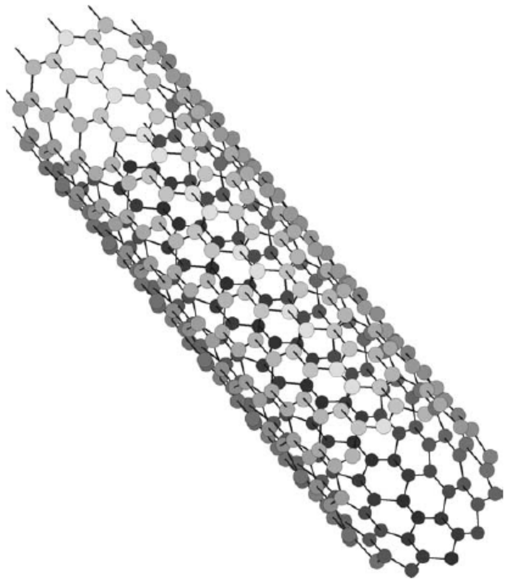

Fig. 5.13a: Schematic of a single-walled carbon nanotube (SWNT)

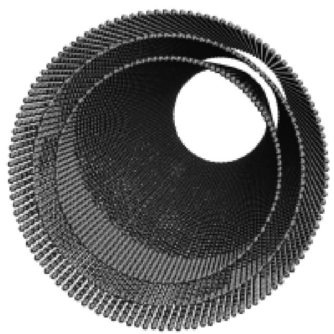

Fig. 5.13b: Schematic of a multi-walled carbon nanotube (MWNT)

[41] Graphite is formed from many layers of carbon atoms that are bonded in a hexagonal pattern in flat sheets, with weak bonds between the sheets and strong bonds within them. Carbon occurs naturally as graphite -- the soft, black material often used in pencil leads -- and as diamond. The only difference between the two is the arrangement of the carbon atoms.

CNTs play an important role in the context of nanomaterials. They have significant advantages over many existing materials because of their novel mechanical, electronic, physical and chemical properties. Regarding to their mechanical properties, CNTs appear to be the strongest material yet to be discovered. They are at least 100 times stronger than steel, but only one-sixth as heavy.

Additionally, nanotubes can also conduct heat and electricity far better than copper, and are being applied in polymers to control or enhance conductivity [5.27].
The unique properties of CNTs can be listed as below:

-High Electrical Conductivity
-Very High Tensile Strength
-Highly Flexible- can be bent considerably without damage
-Very Elastic ~18% elongation to failure
-High Thermal Conductivity
-Low Thermal Expansion Coefficient
-Good Field Emission of Electrons
-Highly Absorbant
-High Aspect Ratio (length = ~1000 x diameter) [5.28]

Apllications:

All of these properties of CNTs cause to intense research around the world on possible applications. Key areas of existing and potential CNT applications include electronics, sensors, structural materials, fillers and storage materials [5.29].

While many of the CNT applications developed for other industries some several uses take also place in construction industry. As mentioned before, CNTs are excellent reinforcing materials because of their extremely high strength, toughness and aspect ratios. The mechanical behaviour of CNT has created great interest in their use as structural materials. Although the potential uses of CNT ropes are still speculative the first applications are likely to be in CNT composite materials. The application areas of CNT in construction industry range from composite materials through high strength structural components to heat transfer technology [5.29].

The most highly developed commercial application for this material is the use of MWNT as a filler material. They can be applied in plastic composites and paints, sometimes as an improved substitute for carbon black. Field emission displays are likely to be the first wide spread use of CNT beyond the current application of MWNT [5.29]. This market has been identified as having a multibillion dollar value.

Polymer, cement and glass are all potential candidates for CNT materials. There is a possibility that CNTs or other nanofibres can provide reinforcement to the glass without interfering with light transmittance [5.29].

The extent of applications for CNT will depend on improvements in synthesis methods. Although reducing costs is the most crucial factor, the ability to produce tubes regularly with high lengths, with specific chirality, and with specific electronic properties will be required for different commercial applications. Other applications will depend both on further research on the applications itself and substantial improvements in CNT synthesis methods [5.29]. The architectural applications of CNTs are presented in Part 6.

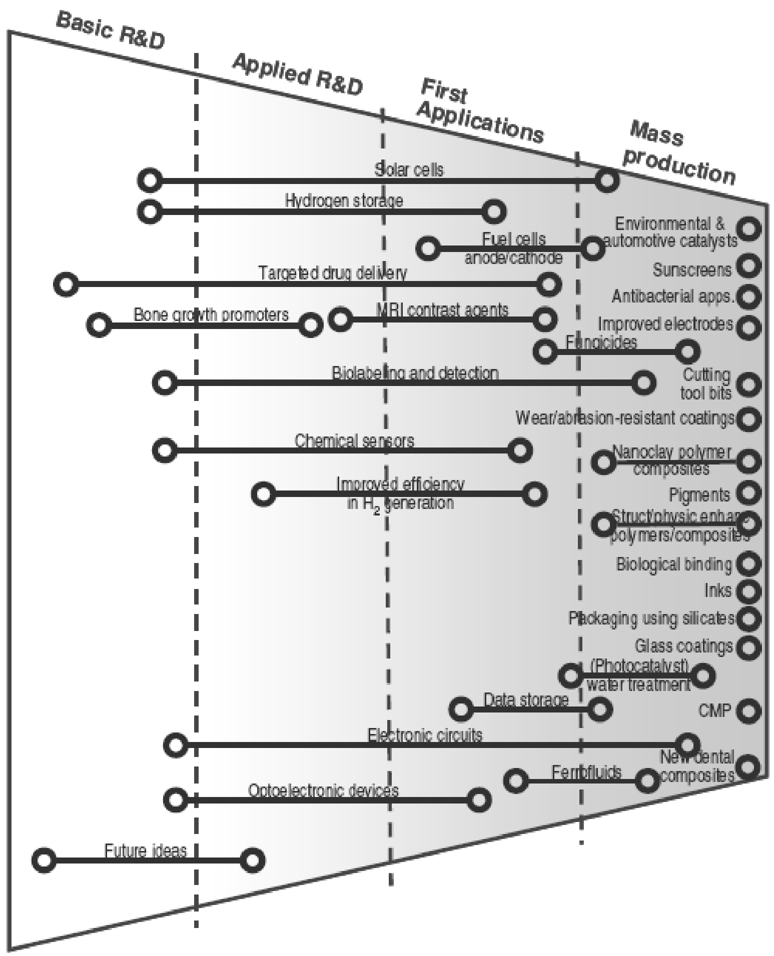

Fig. 5.14: Overview of possible nanoparticle/nanocomposites applications at 2015

5.4.3. Nanoscale In Three Dimensions

5.4.3.1. Nanoparticles

Nanoparticles are microscopic particles whose sizes are measured in nanometres (nm) [5.30]. They are usually defined as particles with a size up to 100 nm. Depending on those sizes the percentage of exposed area in proportion to its total volume changes dramatically when compared to bulk materials. Therefore, they exhibit completely new or greatly improved properties.

Nanoparticles can have several different morphologies such as flakes, spheres, dendritic shapes, etc. They can be made of a wide range of materials such as metal oxide ceramics, metals, silicates and non-oxide ceramics [5.20].

The most usable properties of nanoparticles are related to:

- High specific surface area (very high surface to volume ratio);

-Magnetic and Electric properties (improved/specific magnetic and electric properties);

-Optical properties: (absorption or emission wavelengths can be controlled by size selection);

-Chemical properties (enhanced chemical reactivity) [5.20].

These unique properties cause a range of new and improved materials with a broad of applications and their use includes fields such as:

-Engineering

-Electronics

-Healthcare/medical

-Environment

-Consumer goods

-Energy

At present nanoparticles are being used in some products for example, in antiseptics, in paints, in new coatings (making them scratchproof and unbreakable), and in electrochromic or self-cleaning coatings for windows [5.31].

However, it is obvious that many of these applications are currently at the basic/applied R&D stage and there are still many obstacles that have to be

Fig. 5.15: A family of Quantum dot particles

No colouring agents were added – the receptacles contain only CdSe nano particles in different sizes suspended in hexane. Particle sizes match light wavelengths, and accordingly interact differently with light than is the norm for larger materials. The colour will depend on particle size.

overcome before reaching the market. In 2015, some applications could be at first commercial stage (see Fig.5.14) [5.20].

5.4.3.2. Quantum dots

A quantum dot is a semiconductor nanostructure that contains a tiny droplet of free electrons. It can contain several numbers of electrons ranging from a single electron to a collection of several thousands [5.26]. Regarding to these properties the size and shape of the quantum dots can be precisely controlled. It is so small and therefore an addition or a removal of an electron makes it possible to change its properties in some useful way [5.15]. If they are made small enough, quantum effects come into play, which limit the energies at which electrons and holes (the absence of an electron) can exist in the particles. As energy is related to wavelength (or colour), this means that the optical properties of the particle can be finely tuned depending on its size. Thus, particles can be made to emit or absorb specific wavelengths (colours) of light, merely by controlling their size [5.19]. It can transform the colour of light and exhibits all the colours of the rainbow simply by changing their size: the larger the dot, the redder the light (see Fig. 5.15). As the dots shrink in size, the emitted light becomes shorter in wavelength, moving toward the blue [5.19].

The physics of quantum dots show many parallels with the behaviour of naturally occurring atoms. However, quantum dots can be easily connected to electrodes compared to their natural counterparts. This characteristic makes them excellent tools to study atomic-like properties [5.26]. The quantum dot is considered to have greater flexibility than other fluorescent materials. They are applied in composites, solar cells and fluorescent biological labels which use both the small particle size and tuneable energy levels [5.19].

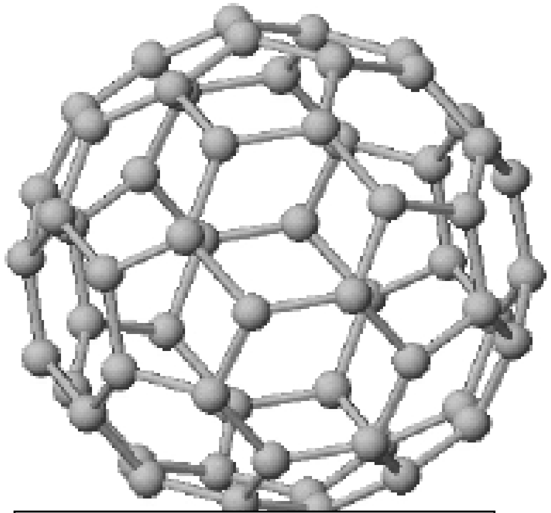

Fig. 5.16: C_{60} Image of a Buckyball

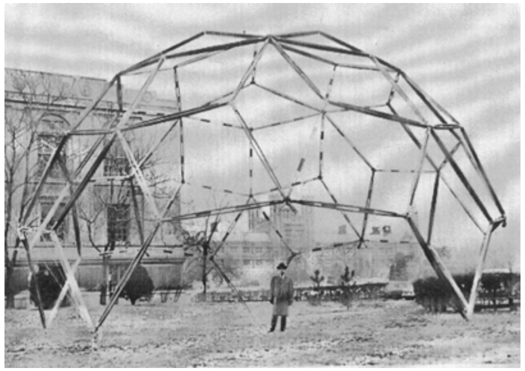

Fig. 5.17: Dome by R. Buckminster Fuller, Washington University, St. Louis, 1954

5.4.3.3. Fullerenes (Buckyball)

Another major scientific development in the field of nanotechnology was the discovery of a new form of carbon called 'buckyballs' or buckminsterfullerenes[42], which are composed of 60 carbon atoms (C_{60}) [5.32]. They are closely related to carbon nanotubes.
The basic C60 structure is a single molecule consists of 60 carbon atoms that link together in the shape of a soccer ball (see Figure 5.16). The structure consists of 32 faces of which 20 are hexagons and 12 are pentagons and has a diameter of approximately 1 nm. Other similar structures have been also discovered such as C70 and C20 [5.33].

Buckyballs are regarded beside diamond and graphite as the third modification of carbon. They composed entirely of carbon and their shape and molecular structure give them special properties.The C60 molecule is extremely stable and has ability to withstand high temperatures and pressures. The exposed surface of the structure enables to react with other species while maintaining the spherical geometry [5.33].
Some potential applications for fullerenes include:

- Catalysts due to their high reactivity
- Superconductors
- Drug delivery systems, pharmaceuticals and targeted cancer therapies
- Lubricants
- Hydrogen storage as almost every carbon atom in C60 can absorb a hydrogen atom without disrupting the buckyball structure, making it more effective than metal hydrides. This could lead to applications in fuel cells

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[42] The structure was named 'Buckminsterfullerene' in recognition of the architect Buckminster Fuller, who was well-known for building geodesic domes, and the term fullerenes was then given to any closed carbon cage [5.19]. In architecture, geodesic domes are known for their strength and lightness. The same is true for buckyballs [5.27].

- Optical devices
- Chemical sensors
- Photovoltaics
- Polymer electronics such as Organic Field Effect Transistors (OFETS)
- Polymer additives [5.33].

Sir Harry Kroto who was a co-winner of the Nobel Prize in Chemistry in 1996 for his role in the discovery of the “Buckyball” defines the potential

‘ If we can solve the technical problem of mass-producing this material, it would revolutionise engineering, because it would be ideal as a building material, for everything from super-light aircraft and cars to ultra-strong bridges and skyscrapers.’[5.34]

In addition, these materials promise major applications in nanoscale electronics. They could revolutionise computing by enabling the creation of highly intelligent, incredibly compact devices. According to Harry, nanotechnology could act revolutionary in saving the planet, with the development of new materials such as “molecular motors” running on protons rather than electrons, as well as more efficient solar cells using C60 as a “dopant” or “doping agent” [5.34].

5.5. Nanofabrication

Iron is known since several thousand years ago, but only in nineteenth century, Bessemer with his blast-furnace, produced these metals in mass quantity. It was a “Top to Bottom” process or from “Total to Parts” [5.35]. However, nanomaterials often require very different production approaches and new tools for fabrication. Nanotechnology represents a new revolutionary approach in the way of thinking and producing and makes it possible to produce materials using methods never applied before. Instead of proceeding from “Total to Parts”, the new goal is acting from “Particle to Part”, adding together atom by atom and molecule by molecule.

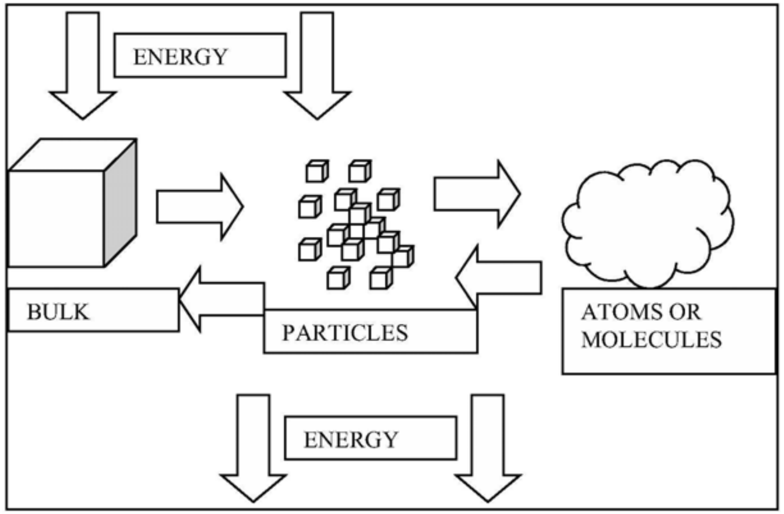


Fig. 5.18: The two basic approaches of nanofabrication

Every manufacturing method is a method for arranging atoms. Today, there are two fundamentally different approaches to manufacturing nanomaterials: and these are '**top-down**' and '**bottom-up**' [5.27].

'Top-down' or *'bottom-up'* approaches show the level of advancement of nanotechnology. Currently most of the industries are approaching a nano-scale through the traditional technologies. These traditional industrial technologies are still mainly at the *'top-down'* stage and this approach is basically an extension of the established method of engineering and microelectronics processing.

Simply, "Top-down" fabrication is to start with a bulk material and then break it into smaller pieces using mechanical, chemical or other form of energy. "Bottom-up" fabrication; on the other hand, use chemical or physical forces operating at the nanoscale to assemble basic units into larger structures [5.15]. With NT bottom-up approach, atoms will be specifically placed and connected, all at very rapid rates [5.36].

The "bottom-up" fabrication deals with the techniques of organizing individual atoms and molecules into particular configurations, to create complex products [5.36]. One aspect of achieving this goal is nanofabrication though self assembly, in which nanomaterials aggregate themselves into larger structures. Another way is the use of sophisticated tools such as the scanning tunnelling microscope or atomic force microscope.

However, bottom-up fabrication techniques are still under exploration. Although quantum dots or nanoparticles can be created using the bottom-up approach the production of computer chips, for example, is not yet possible through bottom-up methods [5.19-37].

The two basic approaches of nanofabrication can be seen in fig.5.18. As component size decreases in nanofabrication, bottom-up approaches provide an increasingly important complement to top-down techniques. There is a whole range of potential obstacles for 'top-down' approach. As the technologies get in touch with smaller sizes, the cost rises rapidly and maintaining the tolerances becomes more difficult

[5.23]. Additionally, this technique is higher in energy usage, produces a lot of waste materials and requires lots of time and production machines [5.23].

5.6. Application Areas

The understanding of the molecular bases of new materials leads to the next generation of high performance materials. It is believed that these advances will bring about a new era of productivity and wealth and will have impact on broad commercial, standard of living and national security aspects. Therefore, nanotechnology is receiving considerable attention by governments, universities and companies around the world. This worldwide interest causes large and rapidly increasing levels of public and private investment. Global government spending has risen during the past decade from under US$1 billion in 2000 to a level of approximately $4 billion in 2004 [5.26]. It is expected to have a market impact of over $ 1 trillion by 2015. The approximate euro equivalent of the NSF's (US National Science Foundation) quoted figures for 2003 are shown in the figure 5. 19 [5.38].

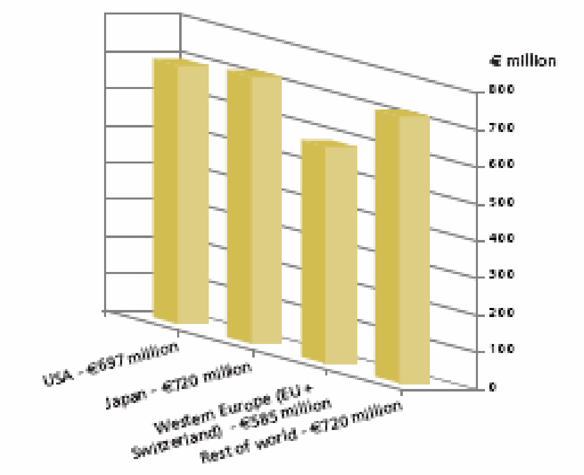


Fig. 5.19: Investment numbers of 2003

These global research and development investments in nanotechnology will affect many important traditional industry sectors. The nanotechnology industry is already quite large, and likely to grow to an enormous scale. In the medium- and long term, nanotechnologies promise a wide range of applications in many industries. In the short term, producing low cost, reproducible manufactured materials with acceptable levels of associated risk (e.g. environmental effects, toxicity) is the main goal [5.39].

A range of applications are currently in the realisation phase, especially with top-down approaches. However, on the other hand, innovative applications – mostly the bottom-up approaches – are likely to emerge only in the medium to long term. Recently, nanoscientists have broadened the application of nanotechnology. Some examples are:

- Materials are much *harder, stronger, more reliable, and safer*. They can be applied to bridges, roads, road signs, and traffic control systems. They last many times longer than our current technology allows

- These smart materials will have condition-based maintenance and will provide new materials capabilities. For example, paints can change color with temperature — white when hot (solar reflective) and black when cold (solar absorptive) — and could provide home heating or cooling adjustments. Additionally, smart windows will create huge energy savings [5.9].

- Intelligent facades (multifunctional and switchable, e.g. photoelectrochromic coatings, heat-regulating, light conductive, useable as lighting and display surfaces etc.)

- Dirt-repellent, or also antibacterial surfaces (e.g. kitchen furniture, sanitary goods,etc.)

- Transparent protective coatings for steel, copper, etc.

- Heating systems (ceramics as components, membranes for fuel cells)

- Photovoltaics (TiO_2 surfaces, Gratzel cells, ...)

- Lightweight construction materials with maximum heat insulation (aerogels, polymer composites, fire-protection walls, nanoencapsulated latent heat stores...)

-Cheap solar cells (dye-sensitised, possibly low efficiency, but high price/performance ratio)

- Efficient, compact energy stores (nanoparticle capacitors with fast charge-discharge characteristic) [5.40].

Various products have been already developed up to now. Some examples of these recent commercial nanotechnology products and some opportunities can be seen below:

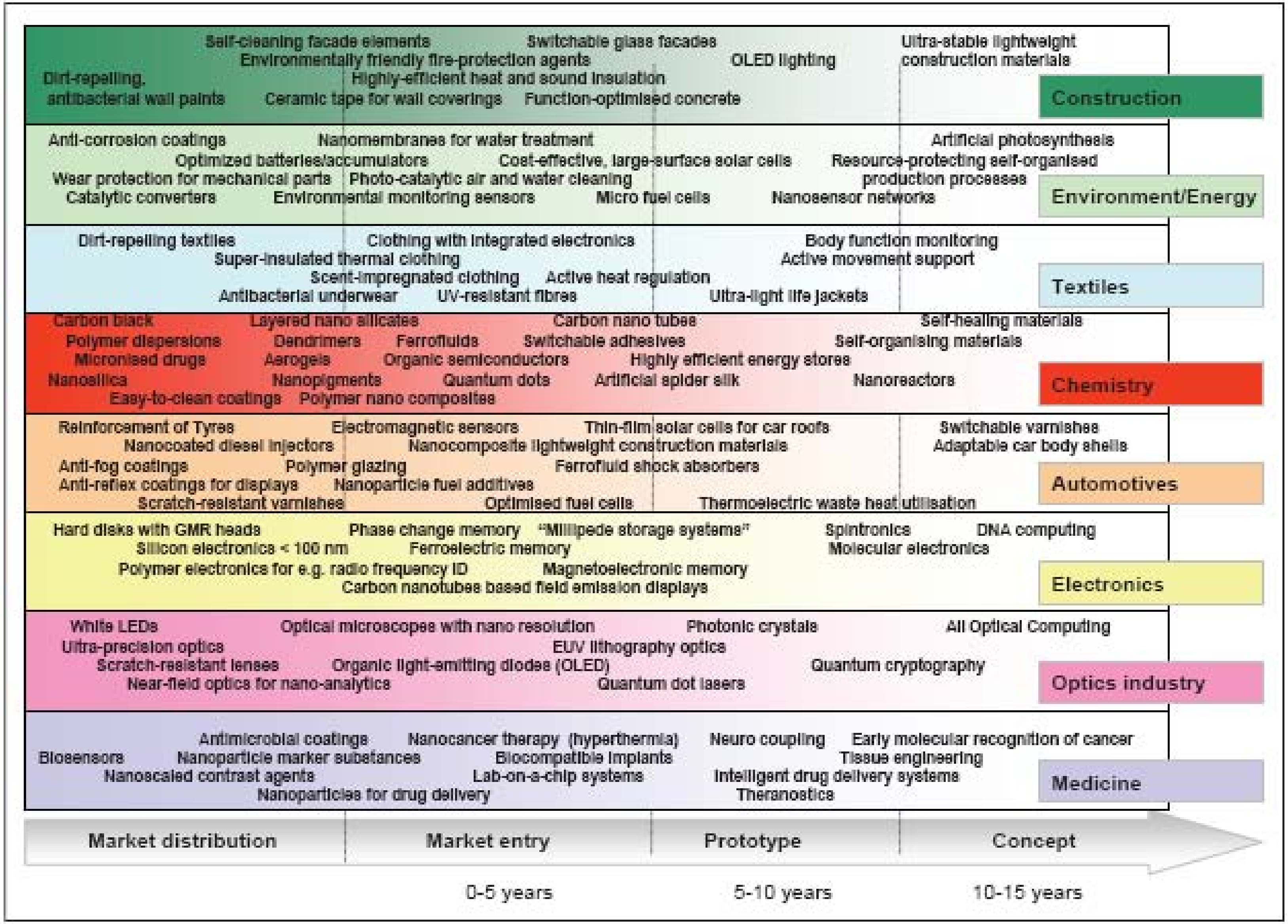


Fig.5.20 : Some examples of application opportunities and degree of maturity of developments in nanotechnology in different industry sectors [5.41].

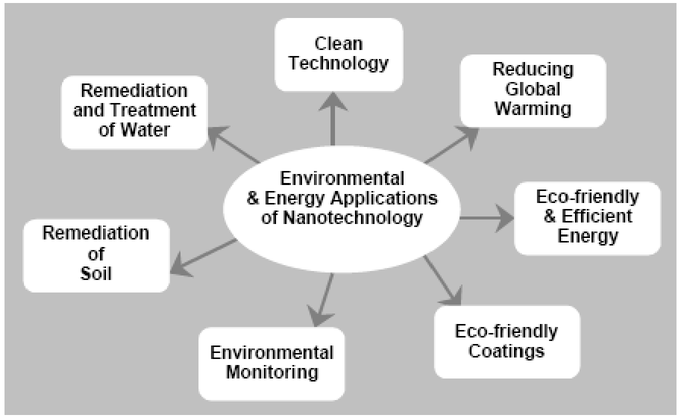
5.6.1. Energy Industry

Global society is heavily dependent on energy and any development in this field is affecting a very wide range of sectors. The increased need for more energy will require enormous growth in energy generation capacity, more secure and diversified energy sources. Therefore, the largest challenge for the modern society is to find ways to replace the slowly, but rapidly vanishing fossil fuels– primarily oil, natural gas and coal- by environmentally friendly alternative energy sources.

Nanotechnology has very wide potentials all along the energy pipeline, from production to transmission, to distribution, conversion and utilization [5.20]. It can offer alternative ways of energy generation, storage and saving. Some key areas of this technology are:

- Highly selective catalysts for clean and energy efficient manufacturing;
- Energy efficient, resource-saving building materials / lighting / glazing;
- Nanocomposites for energy efficient vehicles and engines;
- Low cost fuel cells and batteries;
- Lightweight, efficient solar cells (power collectors and storage); and
- More efficient (1 gigawatt) power transmission lines [5.39].

Below several environmental and energy applications of nanotechnology are shown: [5.36]



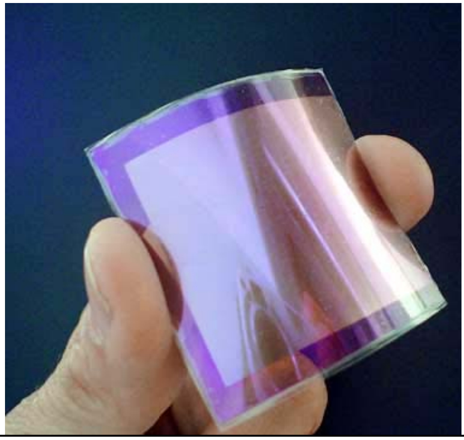


Fig. 5.21: A conforming solar cell produced by Nanosys

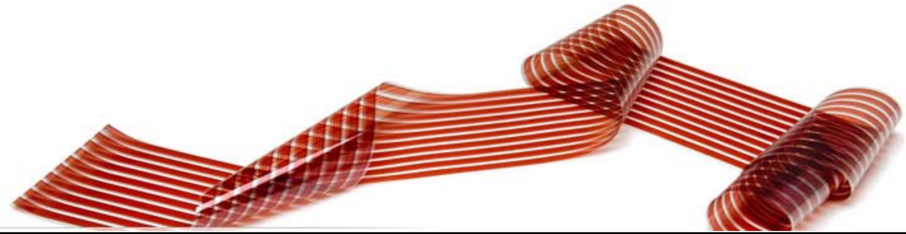


Fig. 5.22: Konarka develops light-activated Power Plastic® that is flexible, lightweight, lower in cost and much more versatile in application than traditional silicon- based solar cells.

One of the most promising areas of nanotechnology is the usage of renewable energies. Nanostructured materials and nanotechnology are contributing to technology development especially in solar photovoltaic electricity production

Regarding to technological developments the efficiency of solar cells can be increased significantly and new designs for low cost solar cells can emerge. They can be made from nanoparticles and nanotubes. Some examples of those new emerging solar cells are nano-composite, quantum well cells, quantum dot cells, dye cells and organic cells.

Various companies like Nanosys, Nanosolar and Konarka are working on "solar nanotechnology" process. With nanotechnology these firms are working on replacing solar-cell modules with rolls of flexible plastic that have photovoltaic elements built in [5.42]. These printed rolls of solar cells would be lighter, more resilient and flexible than silicon photovoltaics and can be used in many applications where traditional photovoltaics cannot compete.
They utilize from the sun's strength and will ultimately provide a cheaper, more efficient source of energy [5.43].

The rods embedded in plastic act like roads for electrons and shorten their route toward the electrode and produce power more efficiently. For example, Konarka is using titanium dioxide nanocrystals coated with a thin layer of a light-sensitive dye. The dye-sensitized solar cells suck up photons even in dim light. [5.42].

It is predicted that due to those products it will be possible to generate required power from the sun while only spending about as much as they do today for non-renewable energy [5.44].

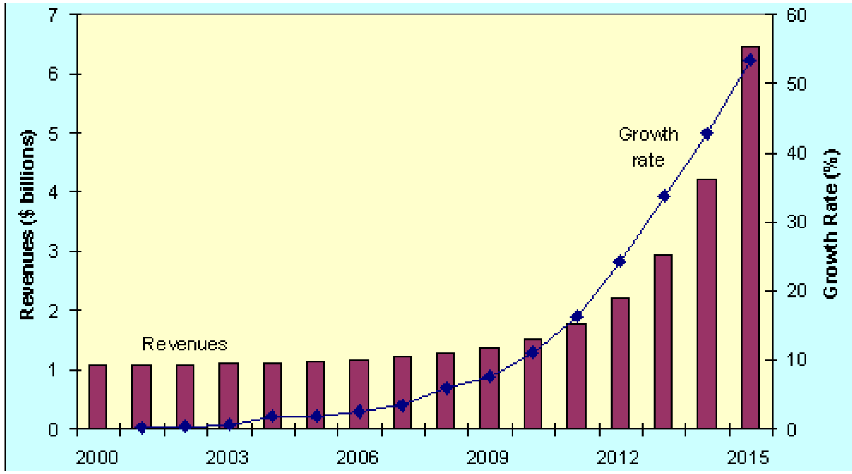


Fig. 5.23: Automotive nanotechnology market: Revenue forecast (Global), 2000-2015

5.6.2. Automotive Industry

The automotive industry is trying to reduce costs, like many other sectors. However, it is dealing with the high price of performance-enhancing technology and environmental compliance. The efficiency and high performance demonstrated by nanomaterials is expected to play a crucial role in dramatically lowering costs and in opening up new opportunities in the automobile sector.

The automotive industry can benefit from nanotechnology solutions and products because of its high performance and efficiency, and in safety and emissions standards [5.45]. The automotive market is a very attractive one and in future nanotechnological competence will be one of the core capabilities required for this industry to remain internationally competitive. As seen in figure 5.23 it is predicted that the nanotechnology revenues in the automotive sector will increase permanently [5.46].

Nanotechnology has already taken place in a number of automotive applications. Many of the proposed applications of this technology are related to automotive industry: stronger, lighter, harder materials (nanocomposites), more efficient use of energy (fuel cells) and new nanoscale catalysts (pollution control) [5.47].

Key drivers in the automotive industry are [5.43]:

- Reduced air pollution
- Recyclability
- Safety
- Better performance and engine efficiency (fuel saving)

The automotive industry can benefit from nanomaterials in several sections: [5.48]

_ Frames and body parts
_ Engines and powertrain
_ Paints and coatings
_ Suspension and breaking systems
_ Lubrication
_ Tires
_ Exhaust systems and catalytic converters
_ Electric and electronic equipment [5.48].

It is expected that the nanotechnology improvements will bring further developments for automobile sector, from the ecology over security up to the comfort

Fig. 5.24: Fields of application of nanotechnology in the automotive industry

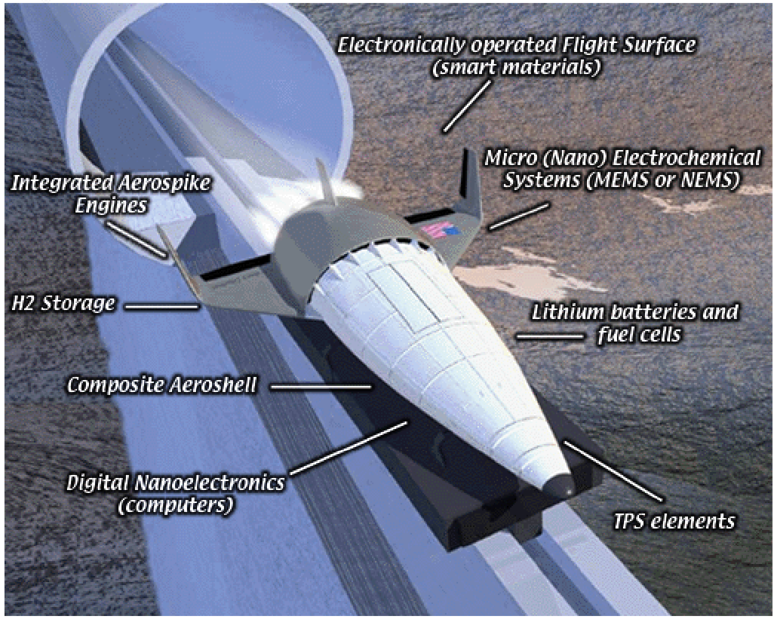


Fig. 5.25: An illustration of a possible future space vehicle

Fig. 5.26: Nanotechnology enables lighter aircraft with reduced fuel consumption space vehicle

5.6.3 Aerospace Industry

In the aerospace industry, there is a great need for the development of novel materials which exhibit improved mechanical properties. However, the possibility of obtaining improved mechanical properties by the conventional methods is almost impossible. To achieve these expectations aircraft companies are looking for new technologies and among those technologies nanotechnology becomes most attractive one. This new technology enables a reduction in costs, novel space missions, testing of new technologies in space and futuristic visions [5.49].

The most important properties addressed by aerospace materials are strength, stiffness, impact resistance, long lifetime, toughness, ductility and lightness.

Main drivers are ranged as:

- increased safety
- reduced emissions
- reduced noise
- increased capacity
- increased range
- enhanced payload
- higher speed
- lower operating and maintenance costs
- better overall management of the aircraft and its use [5.49].

Improvement of lighter materials plays a key role in reaching those aims. Because the demand for lighter materials is strong in space applications, the development of new materials is mainly driven by the space industry. Materials possessing high strength at a reduced mass and size lead to lower costs and make lighter aircraft with reduced fuel consumption.

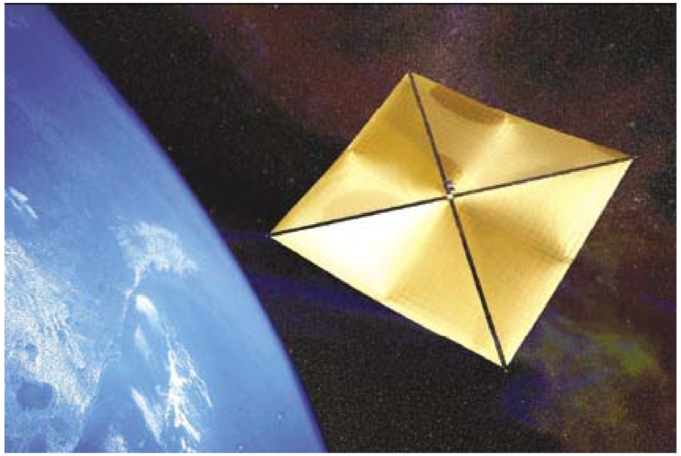


Fig. 5.27: Solar sail - a form of spacecraft propulsion and it uses the sun as light source.

There are some key areas for application in the aerospace industry. One of the most promising is the coating process. It is used to improve durability, reliability and performance of various components; to resist erosion or to improve surface quality; and to produce corrosion resistant coatings for combating pitting, oxidation and hot corrosion. [5.15]

Other key areas are: [5.15]

- Structural materials (e.g. saving weight and energy by using light-weight, ultra rigid materials based on nanotechnology)
    - Light-weight nanomaterials with extraordinary abilities to withstand heat and pressure, used in space shuttle engines
- Information and communications technology (e.g. more efficient design of data transfer between space vehicles and terrestrial information networks using electronic and optoelectronic nanotechnology componenets)
    - Nano-satellites used in monitoring orbiting space vehicles.
- Sensorics (e.g. improving medical monitoring of astronauts with sensors based on nanostructured materials) and
- Thermal protection and control (e.g. improving thermal control systems through nanostructured diamond-like carbon coatings).

The following table summarizes the different nano applications for materials in space under study: [5.49]

Fig. 5.28: Nano-coating protects from water, soiling and stains caused by drinks or food.

Technology	Characteristic	Perspective
Nanoparticles reinforcing polymers	Improve thermal, flame, resistance; decrease permeability, charge dissipation	Short term (in test)
Nanoparticles reinforcing composites	Improve thermo mechanical properties	Short term
Carbon nanotubes reinforcing composites	Improve thermo mechanical properties; radiations resistant	Middle term
Carbon nanotubes reinforcing coatings	Improve thermo mechanical properties; allow creation of electric properties like failure detector	Middle term
Smart materials	Integration of electronic component to create new functions	Long term

5.6.4. Textile Industry

Nanotechnology overcomes the limitations of conventional methods and provides certain properties to textile materials. This promising technology makes it possible to create, alter and improve textiles at the molecular level. This increases the durability and performance of the textiles compared to normal textiles.

New, high-tech textiles attract the market and the increased performance of those products brings added value and additional revenue [5.50]. The first work on nanotechnology in textiles was undertaken by Nano-Tex, a subsidiary of the US-based Burlington Industries [5.51]. This company used nanoscale structures to change the physical properties of clothing. Conventional methods used to impart different properties to fabrics often do not lead to permanent effects, and will lose their functions after laundering or wearing. However, on the other hand, nanotechnology provides some properties imparted to textiles such as water repellence, soil resistance, wrinkle resistance,anti-bacteria, anti-static and UV-protection, flame retardation, improvement of dyeability and so on [5.51].

Another company in the same field is Schoeller Textiles AG, a Swiss textile company and producer of NanoSphere. It is a finishing process that renders fabric

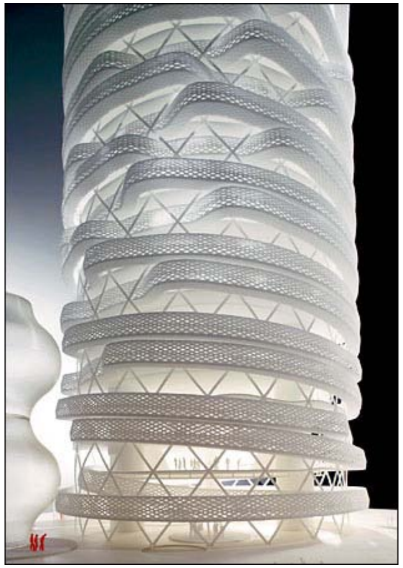
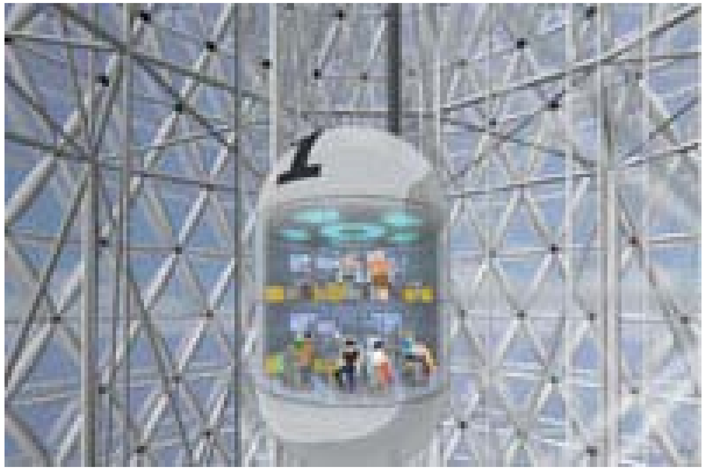
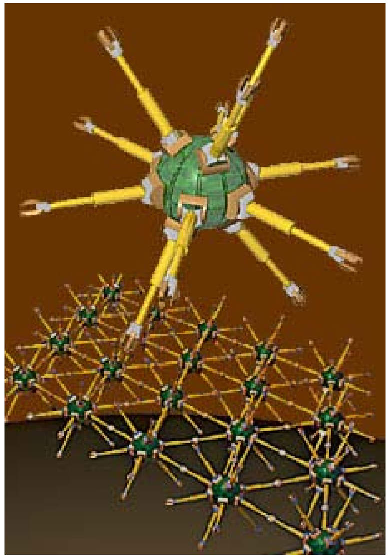
Fig. 5.29: Cleaning of the fabrics from red wine

water-repellent, dirt repellent and anti-adhesive [5.50]. Using this technology, a special three-dimensional structure is created, which enables repelling water and preventing dirt particles from attaching themselves [5.51]. The mechanism is similar to the lotus effect occurring in nature (see details in part six) [5.51].

Definitely, nanotechnology holds an enormously promising future for textiles.
Future developments of nanotechnologies in textiles will have a two-fold focus: [5.52,53]
1) upgrading existing functions and performances of textile materials;
2) developing smart and intelligent textiles with unprecedented function [5.52,.53]



PART 6. ARCHITECTURE AND NANOTECHNOLOGY

PART 6. ARCHITECTURE AND NANOTECHNOLOGY

Technology has the tendency to transform everything and architecture is affected by the thrust of technology through history. This impact has been largely evolutionary and architectural design at all times had to rely on the technology of the time by adapting existing technologies. Architecture presents itself with different materials that made it. The technological development of architecture has been dependent on discoveries surrounding the best capacities of each material.

Research on nanotechnology is key factor for the development of high-tech materials. Nanotechnology has the potential to transform the built environment radically with the developments of these new materials. It is already employed in the manufacture of various items and begins to influence our lives. This technology represents a new revolutionary approach in the way of thinking and producing [6.1]. It is a challenge to think small; like in the past architects will inevitably find the new science of our age unavoidable [6.2].

The Center for Nanoscale Science and Technology defined that *"nanotechnology will lead to fundamental changes in how we live and interact with our environment."* This new technology offers construction professionals the opportunity to design, engineer and build in new ways [6.3]. G. Elvin defines nanotechnology as a matter of design and to understand its full impact it should be examined from a design perspective. [6.3]

Nanotechnology opens the way towards new production techniques, towards new, more efficient and intelligent materials [6.1]. It may change the rules of design and engineering, by specifying the properties and performance of materials and components in advance. The properties of the materials can be improved by introducing characteristic structures on the nanometer scale [6.4]. It challenge existing engineering and design practice.

Currently, construction industry is able to use several technologies such as information technology, modern science, robotics, nanotechnology etc. [6.5]. Among them nanotechnology has the potential to be the Industrial Revolution of the

21st century. Scientific revolutions have transformed the methods and meaning of design and architecture through the history. It has undergone great changes over its history, like in the past, nanotechnology may change design practice. The change may be even more radically with its new materials, with unprecedented new considerations [6.3]. The new goal is being achieved by manufacturing from “small” to “big” adding together atom by atom and molecule by molecule. This allows creating more performing products and processes, within an ideal context of sustainable development [6.1].

There is a need for construction to increase its capacity to develop the capabilities to benefit from nanotechnological applications. This new wave of change will create a continuing series of new breakthroughs with new materials, goods and services. A dialogue is needed across the professionals to understand the nanotechnologies’ full impact on architecture and built environment.

The 1st International Symposium on Nanotechnology in Construction (2003) demonstrated that this new technology has the potential to provide the needs of the construction sector. It is expected that the application of nanotechnology in construction industry will be enormous in the medium to long term [6.6]. Nanoscientists are creating revolutionary materials like coatings a single atom thick, carbon nanotubes which are stronger than steel and quantum dots that could enable us to change the color of almost any object instantaneously [6.7].

The development of carbon nanotubes and other nano enhanced materials have potential to alter building design and performance radically. It can bring dramatic improvements in building performance, energy efficiency and sustainability [6.8]. These improvements include carbon nanotube structural panels, quantum-dot lighting, nanosensors, and more environmentally sensitive buildings [6.7].

Research on nanotechnology will probably provide the basis for a sustainable development of industry [6.1].The construction sector needs research activities in this field to benefit from the great potential for energy savings and sustainable building designs [6.1]. To solve energy problems and environmental problems nanotechnology may provide more efficient solutions.

Future buildings will use more environmentall-friendly materials. “The big issue is sustainability,” said Prof. Harry Kroto, “and we will need much more sustainable technologies in future, with nanotechnology making a big contribution.” [6.9].
Some of the benefits that nanostructuring can bring include;

- lighter, stronger, and programmable materials; less materials will be needed because nanomaterials are stronger and thinner
- reductions in life-cycle costs through lower failure rates;
- most products of nanotechnology will be made of simple and abundant elements, e.g. carbon is the basis of most nanomanufacturing.
- innovative devices based on new principles and architectures;
- use of molecular/cluster manufacturing, which takes advantage of assembly at the nanoscale level for a given purpose. It will allow the targeted creation of materials and products without dangerous and messy by-products.
- cheap nanomaterials of very high strength to weight ratio could provide energy consumption [6.10]

The potential uses of nanotechnology holds the promise of exciting new and sustainable buildings. Nano-engineered materials which have the potential to revolutionize the way we build are already available at the architectural market place. Some examples of the nanoengineered products are;

Self-cleaning glass, flexible solar panels, nano-enhanced concrete, which is stronger, more durable and more easily placed; steel which is tougher; [6.11], smog-eating concrete, and toxin-sniffing nanosensors. The detailed analysis of these materials is presented below.

Through nanotechnology surfaces have enhanced capabilities, like the 'self cleaning' technology. The use of nanotechnology encourages innovations for energy-efficient building and facade design. This technology has the potential to alter the nature of building enclosure and the way our buildings relate to environment and user. Besides from the stronger, lighter materials for structural possibilities, wide area monitoring and environmental control will make great changes in the mechanical and electrical systems with the related impact on architecture. With completely new

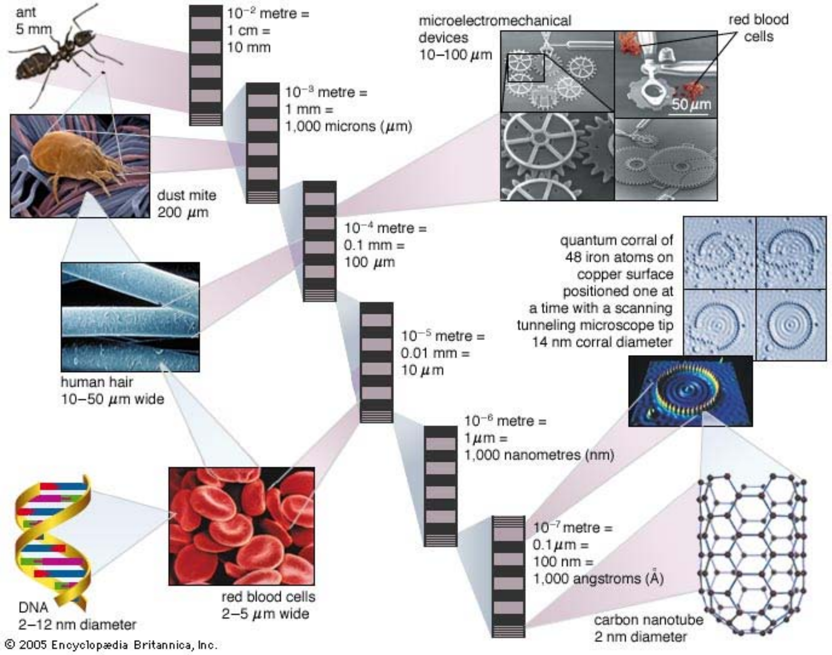


Fig. 6.1: Scale of Nanotechnology

materials and components more durable, efficient, cost-effective and superior buildings can be realized. They have lighter, stronger and fatigue resistant materials that perform better and last longer [6.12]. The prospects for more changes are significant in the near future which has the potential to change how the buildings are erected.

6.1. Nano-Engineered Materials

Nanotechnology change the way materials will be produced in the future. It is the major enabling tool allowing to manipulate, design and engineer materials at scales from 0.1 nm -100 nm [6.6]. As mentioned before, at this scale materials behave differently, they change their traditional physical behaviour because the laws of quantum physics are effective. They can change their color, shape, and phase much more easily than at the macro scale. Therefore it is possible to create new materials which have different properties [6.7].

Nanotechnology is expected to lead to the development of ultra high-performance materials with increased durability and improved performance. It could lead to the development of entirely new productive processes with greater energy efficiency which helps towards sustainable development with better output, reduced use of natural raw materials and less waste generation [6.13]

Materials are construction's core business and construction processes are redesigned to take advantage of the new materials. Already, many building materials incorporate nanotechnology[43]. Many more are in development such as; self-healing concrete, materials to block ultraviolet and infrared radiation, smog-eating coatings and light-emitting walls and ceilings [6.16]. The global market for products arising from Nanotechnology is predicted to reach $1 trillion by 2015 [6.6]. Building construction and operation is estimated to be a trillion dollar per

[43] Nanotechnology can provide tools for understanding basic phenomena and be able to respond to today's challenges. For example, recent work has shown that the Byzantin church of « Hayia Sofia » in Istanbul has such long life because of the self repairing properties of the mortar used almost 15 centuries ago [6.1].

year industry worldwide and it is one of the main industries that will benefit from the innovations offered by nanotechnology and nanomaterials. [6.16]

Recent reports indicate that over 300 nanotechnology-based products have entered the marketplace. These products were worth over $32 billion in 2005 [6.14]. Maybe in twenty years or earlier when materials now in development reach the marketplace they could bring significant impact on buildings. They may include carbon nanotube structural materials, quantum dot surfaces capable of changing color and opacity, photosynthetic and bacteria-based materials, and nanosensors small enough to make any building component “smart”. To predict the full impact of nanotechnology, at the far future, on architecture and our environment is not possible but it is significant to consider. In this part of study it is discussed generally the potential architectural impacts of nanotechnology with its technical implications [6.3-7].

6.1.1. Applications of Carbon Nanotubes

As mentioned before Carbon nanotubes (CNT) are one of the most important materials under investigation for nanotechnology applications. Their unique properties have suggested potential applications in many different fields of scientific and engineering areas. Applications of CNT in construction industry range from composite materials through high strength structural components (cnt ropes).

Nanocomposites are the materials that combine new nanomaterials with available conventional materials. The properties of these composites can be many times stronger than the conventional ones [6.17]. Nanocomposite steel that is three times stronger than traditional steel is already available. Nanocomposite reinforcement of steel, concrete, glass, and plastics will be more advanced with their improved qualities in the near term. These advanced properties will have dramatically improve the performance, durability, and strength-to-weight ratio of these materials [6.7]. Cement and concrete CNT composites have particularly strong potential. Concrete is a complicated, nanoscale structure of hydrates of cement, additives and aggregates and because of its formation it is considered as an ideal candidate for nanotechnology manipulation [6.1]. Various forms of reinforcement, typically in the form of rods or fibers, are added to concrete to compensate for its weakness in tension. The strength of concrete is dependent on a number of factors, such as; the ratio of water to cement, degree and size of porosities present in the cement, the presence of micro-cracking in the binder and the quality of binding of the aggregate to the cement. Cement itself has a complex, nanoscale structure. Some of the properties that affect the strength of cement are expected to act at the nanoscale [6.15].

Improved mechanical performance is one of the benefits expected to be obtained through the application of nanotechnology to cement systems. One approach is the addition of the nanoscale reinforcing materials, which might range from small spheres that would only act to interrupt cracking to nano-fibres or rods. [6.15]. CNT are expected to have several advantages as a reinforcing material for cements as compared to more traditional fibers. First, they have significantly greater strengths than other fibres, which should improve overall mechanical behaviour. Carbon nanotubes can be functionalized to chemically react with cement components, providing routes for other forms of interaction and cement system property control. As with other CNT composites, the major issues to overcome in preparing high quality CNT/cement composites including distributing the CNT within the cement and obtaining suitable bonding between the two materials [6.15].

The production of longer CNTs that can be formed into ropes would create obvious possibilities for various structural applications. CNT strengths and moduli of elasticity would allow for the design of significantly longer spans than existing technology makes possible. Similarly, the use of CNT ropes can be envisioned in improved pre- or post- tensioned concrete structures. Carbon nanotubes for the structural solutions are presented for the construction of space elevators in the part 6.4. CNT appear to be the only material capable of bearing the immense structural loads that would be required in space elevator project [6.15].

Application of nanoscale particles in metals improves the mechanical properties. Possible uses of these materials are suitable for the lightweight construction. Nanometer-thin multilayer coating from conducting polymers protect better against corrosion when using carbon steel or stainless steel as a construction material [6.4].

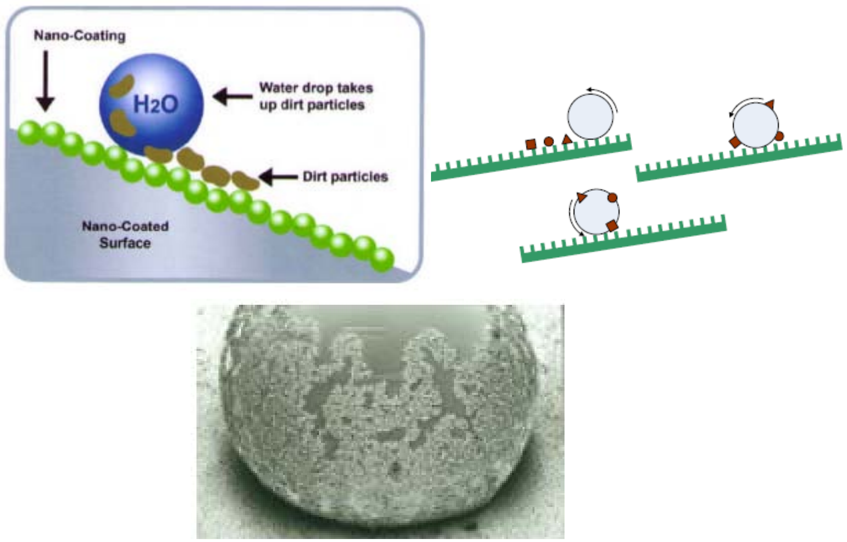


Fig. 6.2: Water droplet with dirt.

Fig. 6.3: Nanotechnology surface treatments can significantly reduce the use of chemical cleaners and save water and maintenance costs. Less cleaning cycles on a tall building means less occupational health and safety risks.

The thermal conductivity of carbon nanotubes presents other applications. Improved thermally resistant composite materials may be possible, since a sufficient density of carbon nanotubes could allow heat to be conducted rapidly away from the contact surface to heat sinks. In the future, it may also be possible to develop insulating materials and heat pipes, taking advantage of the differences in thermal conductivity across the tubes and along their lengths [6.15].

6.2 Nanotechnology and Coatings

As mentioned before coatings are an area of significant research in nanotechnology. Nanotechnology based facade coatings have the potential to change the way buildings are protected and painted. One of the most interested properties for the surfaces is the self-cleaning property. This self cleaning property is obtained by means of coatings and treatments on specific surfaces, which nanotechnology plays a key role. Self-cleaning capacity of these coatings are generally achieved by applying specific nanoparticles (basically silver (Ag) and titanium oxide (TiO2) [6.18]. There are two main categories of self-clean coatings. Hydrophobic coatings repel water and dirt and prevent water drops from drying on the surface and leaving dirt. Hydrophilic water attracting - coatings can be photocatalytically active and break-up organic dirt [6.19].

The development of these coatings is primarily significant in; architecture and construction, textiles, heat exchangers, air conditioning circuits, hygiene-health (hospitals, schools) and food processing [6.18]. These coatings can be used on exterior surfaces to provide a self cleaning effect. Some applications are: glass windows, skylights, exterior walls (brick, concrete facades, granite, tiles or natural stone paved areas). Windows that virtually clean themselves and facades that repel dirt are possible, with this new high-tech surface treatment [6.20]. When the original building materials are coated with a photocatalyst, it provides an invisible shield on hard surfaces like concrete, stone, glass and ceramic, repelling water, dirt and other contaminants.[6.20]That means less need for cleaning, which provides reduction of the water use and the chemical cleaning products. [6.20] These surface treatments are long lasting and invisible, no change to color or optical clarity and they cannot be removed by normal cleaning.

"Human subtlety will never devise an invention more beautiful, more simple or more direct than does Nature, because in her inventions, nothing is lacking and nothing is superfluous."

Leonardo daVinci

Fig. 6.4.: Lotus leaf. An almost ball-shaped water droplet on a lotus leaf. The lotus-effect surfaces repel water, repel dirt, and after a shower of rain the dirt is washed away making the surface clean.

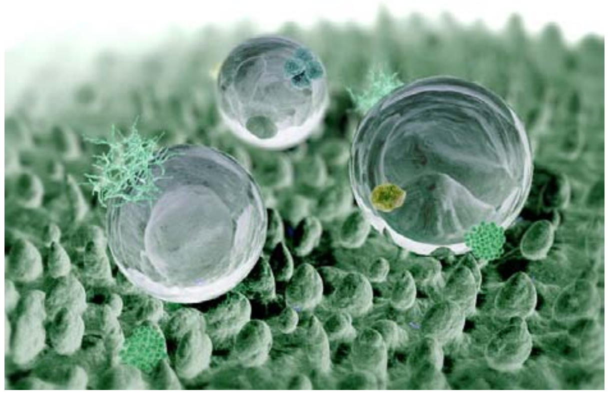


Fig.6.5: Computer graphic of lotus leaf surface. The leaves of Lotus plants are coated with wax crystals around 1 nanometres in diameter that repel water.

Nanotechnology, like other branches of science, is mainly concerned with understanding nature and how it works. The principle of self-cleaning surfaces was discovered by botanist Prof. Wilhelm Barthlott who researched the Lotus-Effect of the lotus plant's leaves [6.22]. He discovered that lotus leaves stay clean not because they are smooth but because they have microstructures and nanostructures that make the surface rather rough.

The surfaces of Lotus plant leave have a self-cleaning mechanism because they are engineered by nature to be super-hydrophobic. The leaves remain clean, although they grow in muddy rivers and lakes. They have a natural self-cleaning mechanism; their microscopic structure and surface chemistry mean that the leaves never get wet. After a shower of rain they immediately appear dry and clean, as water runs off them like marbles of a glass plate, taking away the mud, tiny insects, and contaminants with them.

Two physical properties cause this non-wettability:
1. Very fine microstructures on the leaf surface repel water
2. Nanotructures (1nm) on top of the microstructures are coated in a waxy substance making the leaves super-hydrophobic

This biological approach opened up a broad field of possible industrial applications. To applicate the Lotus-Effect into coatings, it is necessary to create a surface with the appropriate nano-structure. Nanotechnologists creating artificial methods to engineer surfaces with similar surface properties. Extremely fine microstructured finishes applied to materials that imitate the surface of lotus leaves which can stay dry and clean themselves in the same way as the lotus leaf. These surfaces are advantageous in various applications like facades, roofs, paints, glasses etc

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Fig.6.6: Self Cleaning Glass

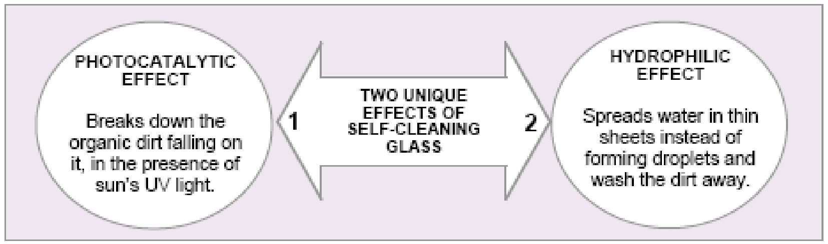


Fig.6.7: Two unique effects of self cleaning glass. The self-cleaning glass is similar to ordinary clear float glass, but it has two unique effects, which are outlined in the above figure.

6.2.1. Self-Cleaning Glass

Surface coating with different types of films improves various properties of the glass. Examples are antireflection coatings, which lower the high reflection of glass; low-e coatings, which reduce the heat losses; and cold light reflector coatings, which take the infrared portion out of the electromagnetic radiation. Nanotechnology is seen as an important source for new coating possibilities in glass industry. Thin films and coatings increase the strength of glass in high-temperature applications and prevent windows from becoming dirty and reduce or eliminate the need for cleaning. Self-cleaning glass provides better performance in use, particularly in tall buildings.

Self-cleaning glass is essentially a coated glass with photocatalytic and hydrophilic properties. Grime is broken down by a daylight activated reaction with the surface coating of titanium oxide [6.12]. As mentioned before the coating creates a photocatalytic process by reacting with ultra-violet rays, breaking down organic dirt. The second part of the process occurs when rain falls on the surface. The water spreads across it, rather than forming droplets because the glass is hydrophilic. It then runs off, taking the dirt away with it [6.12]. Ordinary glass is water-repellent (hydrophobic; water does not cover it smoothly, but tends to form droplets. The self-cleaning glass is coated in molecules that attract water and encourage it to spread out. The rain covers the surface evenly, dissolve what the photocatalyst made of the dirt, and run off in sheets. This coating can last for the lifetime of the window [6.22].

After years of development these self-cleaning windows have come on the market in the past years. Major glassmaking industries developed new processes. Pilkington's Activ glass was the first product to be introduced, followed by PPG Industries' SunClean glass. However, it will take time for the features of the technology to become widely known and accepted in the market like every new emerged technology [6.24].

Fig.6.8: in Beijing, China's National Opera Hall features self-cleaning glass coated with a film of photocatalytic nanoparticles that can break down dirt.

Fig.6.9: Nanotec Surface treatment for concrete and stone surfaces

A TiO_2 layer on the order of 100 nm or less in thickness is added in the manufacturing process while the glass is still in the molten state. The TiO_2 is integrated into the glass surface and doesn’t wear off. This thin layer leads to two unusual effects that promote cleaning. [6.24]The material deposition of the coating on the glass has been designed to allow the glass to perform its primary function of letting in light and providing transparency. The functions of breaking down dirt and allowing it to be washed away were designed to work without detracting from the primary function. [6.12]

6.2.2. Different Surface Treatment with Nanocoating Solutions

Nanocoatings are applied to insulate both new and existing materials. They can protect materials such as concrete, wood, metal, and masonry etc. Contamination can be removed much easier with nanocoatings [6.7]. An Australian firm Nanotec produces a range of nanocoatings for protecting wood, metal, concrete, glass and textiles. These effective treatments offer physical enhancements for a broad range of products such as:[6.25]

Nanoprotect CS (Concrete&Stone): this nanotechnology surface treatment is water-based, transparent and appropriate for porous and non-porous concrete and stone surfaces. The hydrophobic effect creates self-cleaning properties but it is still permeable to water vapour. Nano particles adhere directly to the substrates molecules, assembling into an invisible, ultra-thin nanoscopic mesh. Nanoprotect CS molecules are very small and high penetrating. The slow water evaporation rate allows it to enter even the smallest pores. The water permeability allows the surface to ‘breath’ naturally. It protects and preserves the substrate without altering the natural surface texture, colour or slip resistance. Water runs of easily from the treated surface. Dirt particles are washed of by rain or when rinsed with water, with self cleaning properties. It can be applied on concrete, cement rendered concrete, sandstone, brickwork and natural, cast stones etc [6.25].

Fig.6.10: Nanotec Metal treatment

Fig.6.11: Nanotec Wood treatment

Fig.6.12: Nanotec Plastic treatment

Nanoprotect Metal 2in1 is a semipermanent hybrid nanotechnology treatment where. It provides long-term corrosion protection and anti-fingerprinting properties on natural, brushed and polished metal surfaces. It is an ultra thin and transparent modification of the surface structure on a molecular level but it is not a sealer. The treatment is resistant to friction, is UV stable and handles temperature changes. Water or other cleaning agents cannot remove it. Treated surfaces repel water, oil and other contaminants creating a self-cleaning effect. It is a protective treatment for steel, stainless steel, aluminum, titanium, aluminum, silver, brass, copper chrome and many other bare metal surfaces [6.25].

Nanoseal Wood is a transparent water-based nanotechnology surface treatment with high penetration depth for wood. Like the other products of Nanotec it is also not a sealer. The hydrophobic effect creates self-cleaning properties and also decreases timber swelling and shrinking that lead to cracking and warping. The treatment allows wood to resist decay and discolouration by wood-decay fungi which require moisture to survive. The treated surface can't be penetrated by moss, algae and fungi formation. The treatment is also resistant to friction and water or normal cleaning agents cannot remove it [6.25].

Nanoprotect Plastic is a transparent alcohol based nanotechnology treatment for plastic, Plexiglas and polycarbonate surfaces. It contains no silicon, teflon, wax, oil or fluorocarbon. It provides long lasting protection against the build-up of dirt and lime deposits, and stops salt calcification damage [6.25].

Researchers at the MIT have developed a unique polymer coating which is made of silica nanoparticles. This coating has the potential to provide the first permanent solution to the fogging problem says the research leader Michael Rubner. He emphasized that the coating basically causes water that hits the surfaces to develop a sustained sheeting effect, and that prevents fogging. The coatings have alternating layers of silica nanoparticles. In the coating they strongly attract the water droplets and force them to form much smaller contact angles with the surface. Thus, the droplets flatten and merge into a uniform, transparent sheet rather than forming countless individual light-scattering spheres. The same coatings also can be

Fig.6.13: Dives in Misericordia Church in Rome

Fig.6.14: The Hong Kong Subway System

engineered to have superior anti-reflective properties. They can reduce glare and maximize the amount of light passing through. Researchers are currently working on processes to optimize the effectiveness of the coating for all surfaces. However, they emphasize that more testing is needed [6.26]. There are plenty of ongoing researches that need more testing, time and investment for the commercial production.

Nanotechnology is being applied to architecture through manufactured building products that have unique performance characteristics. Dives in Misericordia Church in Rome (fig.6.13), designed by Richard Meier & Partners Architects, uses the catalytic properties of titanium dioxide that feature self-cleaning concrete simply by reacting to sunlight. Photocatalytic titanium dioxide nanoparticles in the precast panels (manufactured by Italcementi) make them shed dirt. The panels trap airborne pollutants in a nanoparticle matrix on their surface, and then decompose them. This intervention is an innovative way to offset emissions from the manufacture of cement [6.7].

The Hong Kong subway system has coated its cars' interiors with titanium and silver dioxide coatings. It has the potential to kill most of the airborne bacteria and viruses they come into contact with [6.7].

Fig.6.15: Aerogel recognized as the lightest-weight and best insulating solid in the world.

Fig.6.16: Aerogel eliminate transmission of UV rays

6.3. Nano Insulation

Aerogels: Aerogels are composed of micro-porous networks made up of interlocking nano-scale filaments. Because of their low density and porous nature aerogels have the ability to stop high velocity particles, and this make them highly efficient thermal barrier. They consist of different materials like silicates or carbon. Aerogel has been used in space industry. It used as the thermal insulation material in the 2003 Mars Exploration Rovers. It is an ongoing unmanned space mission, which explores the surface and the geology of Mars. Aerogel is critical to its overall design with its insulating capacity [6.27].

Nanogel insulation, made by the Cabot Corp., is a form of aerogel. Its low solids content and extremely small pore size (20-40 nanometers) make it ideally suited for a wide range of insulation applications. Nanogel is 5 percent solid and 95 percent air. The high air content means that a translucent panel 3.5 inches thick can offer a high insulating value [6.7]. It manages heat transfer, diffuses light, reduces sound and repels moisture. Manufactured in particulate form, in grades ranging from opaque to translucent, it can be easily adapted for use in a variety of applications [6.28].

In Arizona J. Lincoln Hospital’s westward facing wall of waiting room was affected to the intense solar heat gain and excessive glare (fig.6.16). The desire to improve the performance of the channel glass wall system, the aerogel insulation system was retrofitted into the channel cavity. With the Nanogel panels placed between the channel glass, the glare was immediately cut down and the solar heat gain was noticeably reduced [6.28].

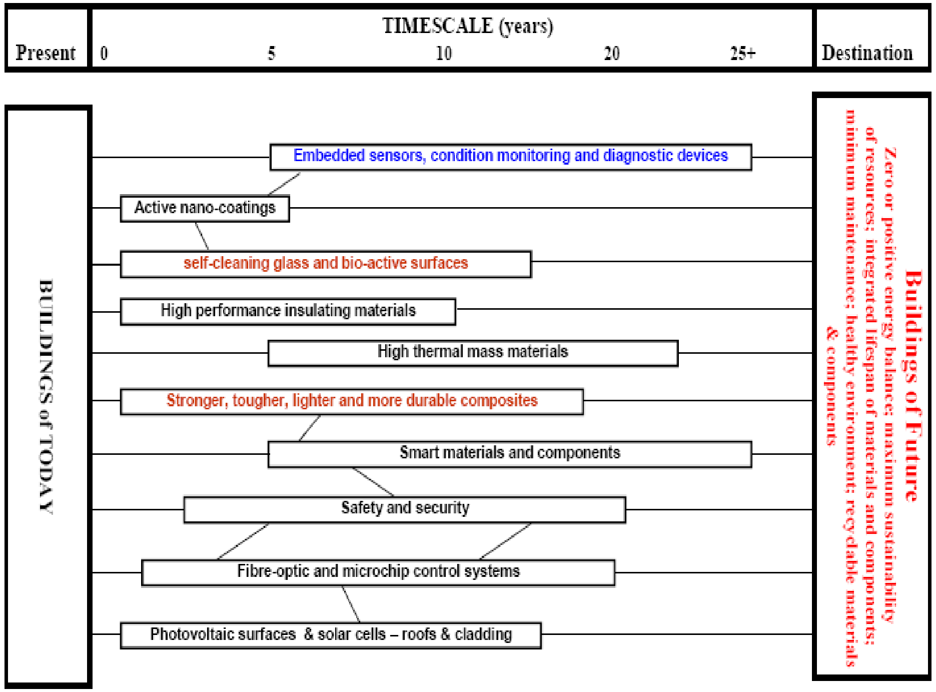


Fig.6.17a: The near future of nanotechnology

6.4. The Near Future of Nanotechnology

Scientific revolutions have transformed the methods and meaning of design and architecture throughout the history. Nanotechnology has the potential to change design practice like in the past. The change may be even more radically with its new materials, with unprecedented new considerations. The properties of the conventional materials can be deliberately improved by introducing characteristic structures on the nanometer scale. This technology can be seen as the Industrial Revolution of the 21st century because of its great potential to create a range of materials with novel characteristics, functions and applications. It has the potential to change the rules of architectural design practice and also other professions' traditional design parameters. A common work between various disciplines (civil, structural, environmental, electrical and mechanical engineering) will play a key role to achieve the maximum benefit from this new technology.

The numbers of nano-related patents are increasing enormously. In the near future, nanotechnology will offer architecture an abundance of smart materials that will be precisely engineered to perform specific tasks. As mentioned before, this is already happening. Carbon nanotubes and other nanomaterials could so radically transform the built environment because of their remarkable properties. Carbon nanotubes offer the promise of an outstanding combination of strength, stiffness and toughness which will be revolutionary for new structural solutions. However, it will take time to overcome the manufacturing and engineering problems for their widespread adoption like in the history of the development of other advanced materials.

Over the past the impacts of technology on the construction sector have been largely evolutionary. In the future, however, there is a high potential for significant developments that will change the basic nature of construction. For the future of tall buildings, which is presented as a case building type, it can be expected that more innovative tall buildings will be built particularly in high density cities. Tall buildings are becoming taller, more complex and more sustainable by utilizing the latest technology. Recent proposed projects show an evolution from tall buildings to megastructures. The range of the heights of these recently proposed megastructures

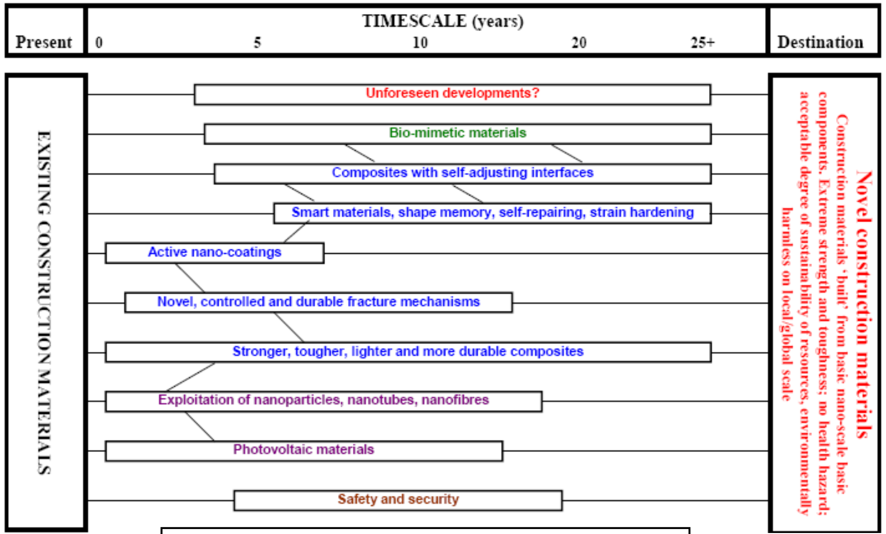


Fig.6.17b: The near future of nanotechnology

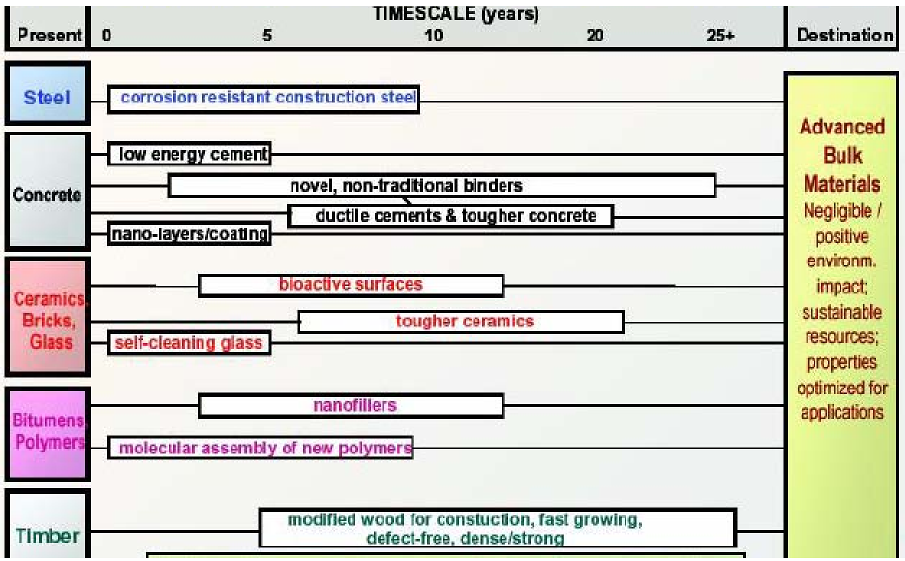


Fig.6.17c: The near future of nanotechnology

are from about 600m tall Holonic tower to 4000m tall X-Seed 4000 [6.23]. These structures can be defined as an extremely large multi-use tall building which contains almost a city within it. It can be expected that the building height will be continuously increased in conjunction with the improvements in technology in structural systems, materials and energy efficiency [6.23]. Nanotechnology has the potential to achieve these demands. This technology can offer especially beneficiary solutions for these buildings. Nanotechnology will become a driver of change in the construction industry by the understanding of materials and controlling their structure at the nanoscale.

A common work between various disciplines will play a key role to achieve the maximum benefit from this new technology. The designers of future buildings must be aware of current trends to create more innovative and efficient solutions. It is significant understanding the fundamental principles of architecture-related disciplines. A dialogue is needed across the professionals to understand the nanotechnologies' full impact on architecture and built environment. Various products such as self cleaning materials, nano-sensors, nano-solar-cells and many others would be inevitable design elements at the near future. Some projects are presented below which can help to imagine the impact of nanotechnology on architecture at the near future.

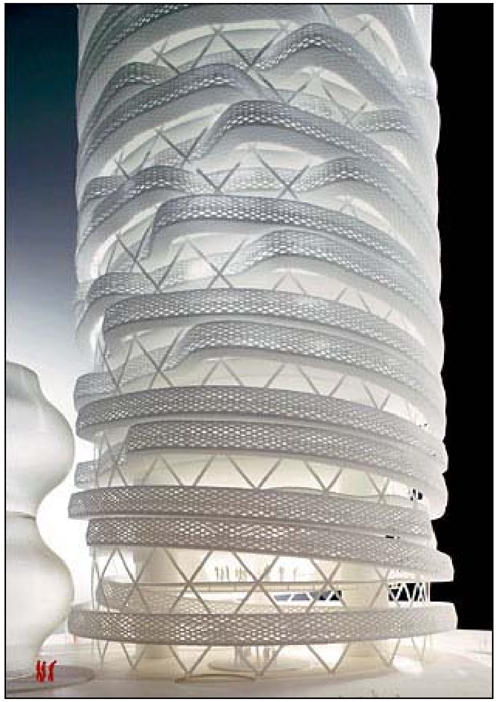
Fig.6.18: Concept design of the Nanohouse

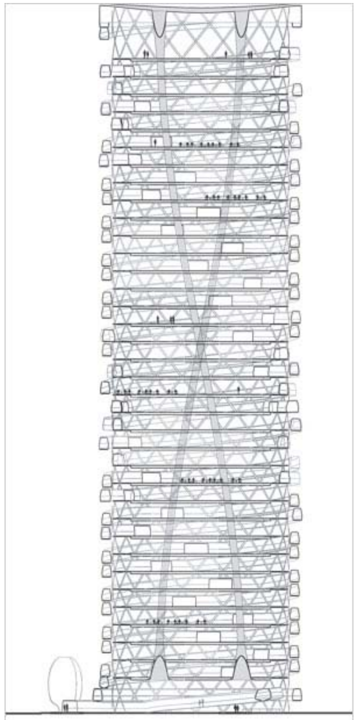
Nanohouse

Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) and Sydney's University of Technology launched the “Nanohouse” in 2002 to demonstrate the applications of nanotechnology and their interaction with traditional building materials.

“The principles upon which it is based are energy efficiency, sustainability, and mass customisation” says the project leader Carl Masens.[6.29] Architect James Muir visualised the nanohouse it features a range of nanotechnology-based products such as;[6.30]

- UV/IR filtering and reflecting windows for control of unwanted solar heat gain
- Self-cleaning TiO_2 coated glass -Self-cleaning tiles
- Protective coatings for furniture offering UV protection
- Cold lighting systems for the harvesting of daylight during the day and use with ultra efficient bright white LED light sources
- Water quality control systems that remove pollutants from water, and clean effluent water
- Light coloured nano-particulate paints without glare and dark pigments for paints that do not retain heat [6.31]





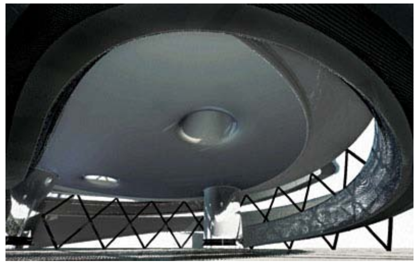
Carbon Tower

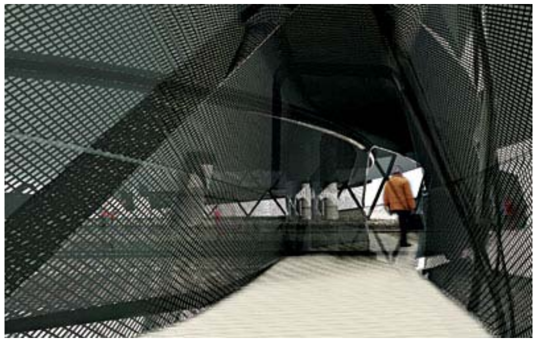
The “Carbon Tower” Prototype is a 40-story mixed-use tower that incorporates five innovative systems:

- pre-compressed double-helix primary structure,
- tensile-laminated composite floors,
- two external filament-bound ramps,
- breathable thin-film membrane, and
- virtual duct displacement ventilation.

Studies are conducted by Arup. It is suggested that, if built, the tower would the lightest and strongest building of its type [6.32].

Architects Testa and Weiser are pursuing a systemic examination of intermediate-level building systems in collaboration with industry. The carbon tower project was envisioned with that strategic thinking. "*The [construction] industry isn't completely fixed. If one finds applications for materials that are provocative and at a big enough scale, it is possible to engender new divisions of industry*," says Testa. "*We are interested in things that are realizable. We are trying to reach different actors and trying to create something the industry can understand and rally around*." [6.32].





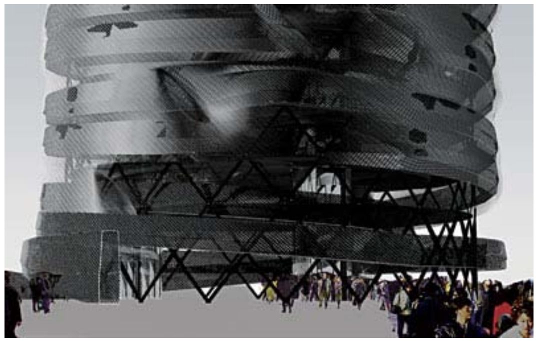


Fig.6.19: Carbon Tower

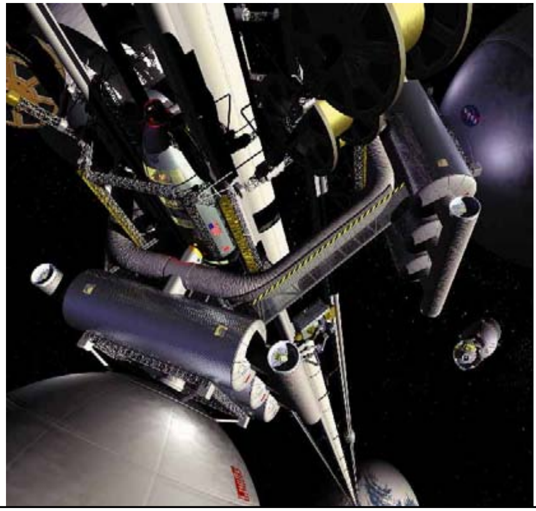


Fig.6.20: Artist Pat Rawling's concept of a space elevator viewed from the geostationary transfer station looking down along the length of the elevator toward Earth.

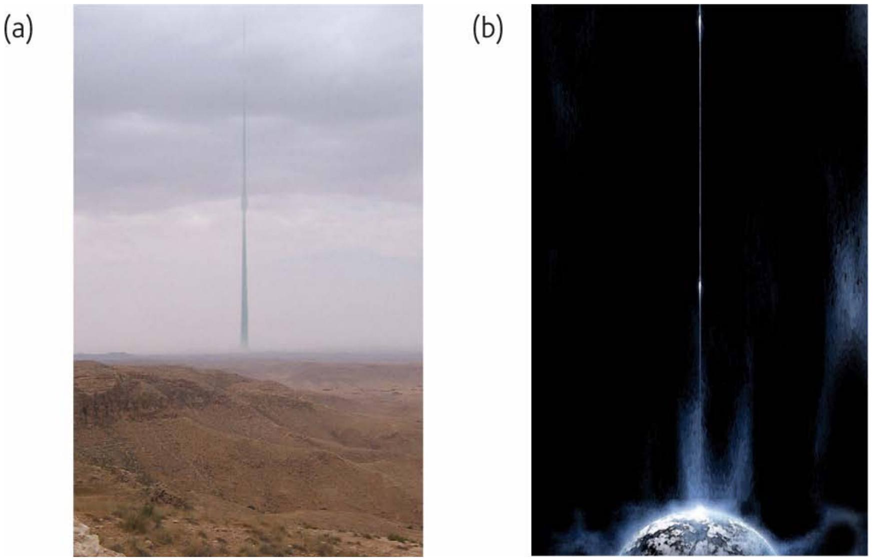


Fig.6.21.: The space elevator concept. Artistic representations (a) from the Earth and (b) from space. (Courtesy of Studio Ata, Torino, Italy.)

Space Elevator

Space elevator is the most appropriate symbol of the promise that nanotechnology will revolutionize the world of structural materials [6.33]. It requires a material with very high strength-density ratio that no existing engineering material can provide. Materials technology needed for this construction is in the development process in laboratories. NASA has been developing nanotubes for years and Space Elevator is a bold proposal put forward by NASA, by using carbon nanotubes [6.2].

A space elevator is a mega cable from our planet's surface into space at 35,786 km in altitude. Its center of mass is at the geostationary point such that it has a 24-hr orbit. It stays over the same point above the equator as the Earth rotates on its axis [6.35]. The vision is that a space elevator would be utilized as a transportation and utility system. Electromagnetic vehicles traveling along the cable could serve as a mass transportation system for moving people, payloads, and power between Earth and space [6.35].

Designing the cable is the most important part of the space elevator. The cable must have a very high strength and low density. It is considered that the cable has a constant section and a vanishing tension at the planet surface and the maximum stress at the geosynchronous orbit.

The idea of building a tower from the surface of the Earth into space dates back to the earliest manuscripts. The writings of Moses reference an earlier civilization that in about 2100 BC tried to build a tower (commonly called Tower of Babel) to heaven out of brick and tar. This idea has been dreamed of, invented, and reinvented many times throughout modern civilization [6.35].

The key concept of the space elevator was first conceived in 1895 by a Russian scientist Konstantin Tsiolkovsky who was inspired by the Eiffel Tower. He suggested a fanciful "Celestial Castle" in geosynchronous Earth orbit attached to a tower on the ground (up to an altitude of 35,790 km).

Another Russian, Yuri Artsutanov, wrote some of the first modern ideas about space elevators in 1960. In 1975, Jerome Pearson, working at the Air Force Research Laboratory, also invented the space elevator and published a technical

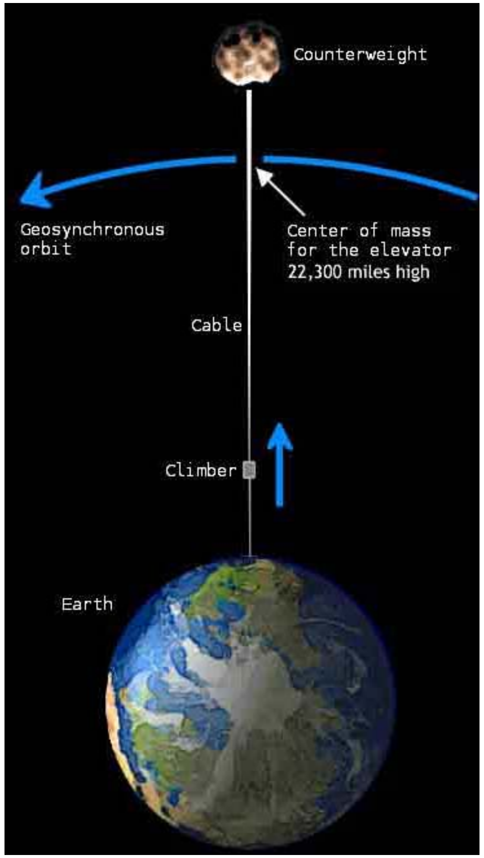


Fig.6.22: Space elevator model

paper. This publication inspired Sir Arthur Clarke to write his novel, The Fountains of Paradise. It was about a space elevator based on a fictionalized Sri Lanka. Pearson participated in the NASA Marshall Tether workshops beginning in 1983 [6.35].

David Smitherman's (of NASA/Marshall's Advanced Projects Office) publication, Space Elevators: An Advanced Earth-Space Infrastructure for the New Millennium, is based on findings from a space infrastructure conference held at the Marshall Space Flight Center. (2000). According to Smitherman, construction is not feasible today but it could be toward the end of the 21st century. "*What the workshop found was there are real materials in laboratories today that may be strong enough to construct this type of system*," said Smitherman. [6.34]

In a 1998 report, NASA applications of molecular nanotechnology, researchers noted that "maximum stress [on a space elevator cable] is at geosynchronous altitude so the cable must be thickest there and taper exponentially as it approaches Earth. The desired strength for the space elevator is about 62 GPa(Giga-Pascals, a unit of measurement for tensile strength). Carbon nanotubes have exceeded all other materials and appear to have a theoretical strength far above the desired range for space elevator structures. "The development of carbon nanotubes shows real promise," said Smitherman. [6.34]

The Earth to GEO space elevator is not feasible today, but could be an important concept for the future development of space. The feasibility of the space elevator is currently possible only with the use of nanotubes. For possible space elevator construction the time frame is assumed to be more than 50 years, in the latter half of the 21^{st} Century [6.36]. The technology paths are beneficial to many other developments. It has the potential to yield incremental benefits as progress is made toward making space elevator construction feasible [6.35].

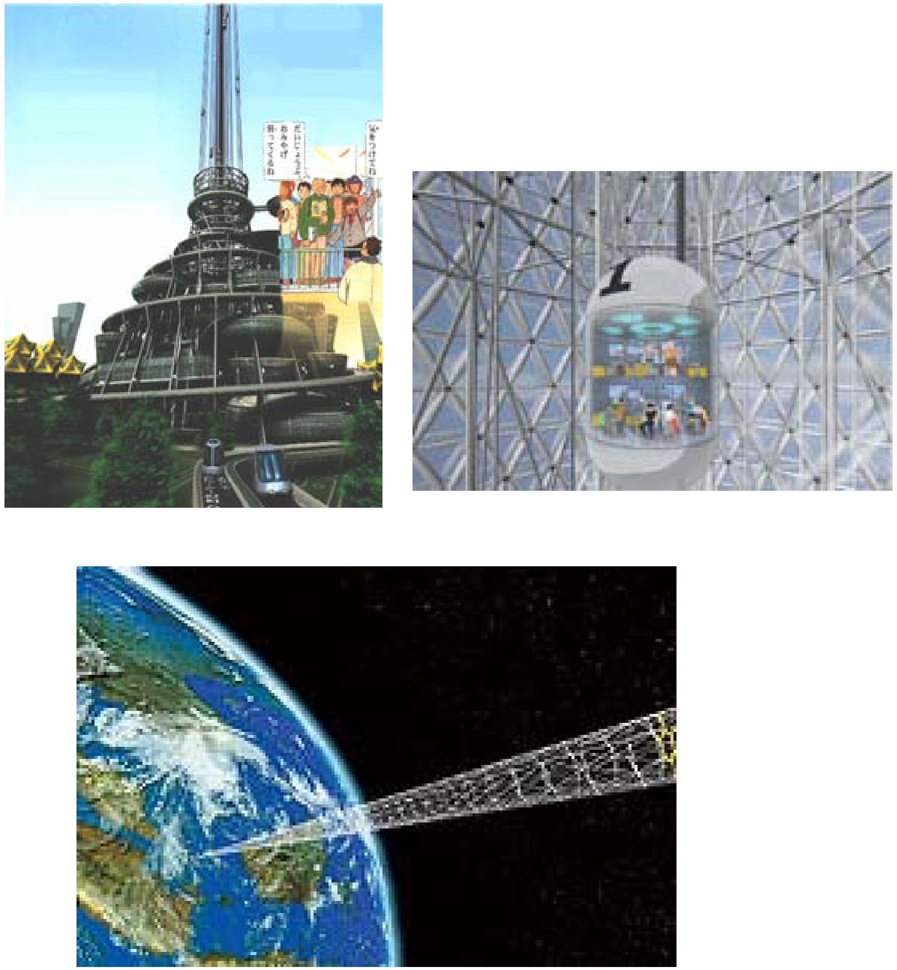


Fig.6.23: The animation movie ATA Space Elevator

An international team of scientists and artists created a science animation film to portray the landscape of a futuristic city never before seen. It aims to contribute children education. On August, 2006 the Japanese National Museum of Emerging Science and Technology in Tokyo has started to show the animation movie 'Space Elevator', based on ATA Space Elevator Project. The project is directed and edited by Dr. Serkan Anilir. This movie shows a possible image about the cities of future. It places the space elevator tower as a new infrastructure into the city planning. Currently, the movie is shown in all science museums in Japan [6.37].

Fig.6.24: Self assembly is everwhere in nature

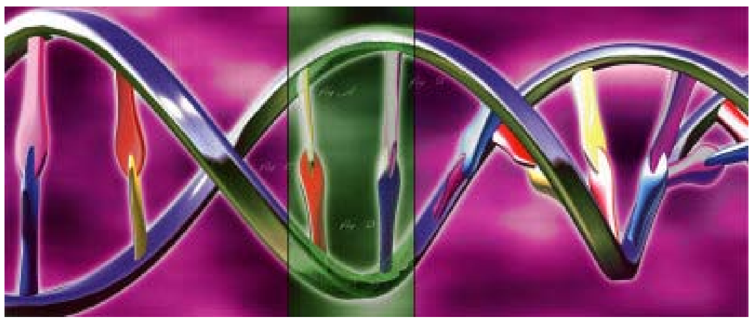


Fig.6.25: formation of the DNA double helix is made by self-assembly

6.5. The Far Future of Nanotechnology

It is not easy to predict the far future of any technology but it is obvious that in the medium- and long term, nanotechnology has the potential to impact on a wide range of applications in many industries. Although the emergence of atomic-precision manufacturing is not on an industrial scale it is predicted that nanotechnology will be a large part of the future. Because physics and chemistry allow it, it will bring great improvements in all technologies [6.49].

The ability to design and build complex things at nanoscale provides tremendous advances in quantum information processing, nanobiotechnology, self-assembly and nanofabrication [6.44]. To understand the potential of far future nanotechnological improvements, understanding basic principle of self assembly is particularly significant. This revolutionary manufacturing method opens new scientific frontiers and offers many opportunities.

Self Assembly

Nature builds sophisticated materials and machines which have trillions of nanoscale components. Self-assembly process is everywhere and it can occur spontaneously. Components "self-assemble" in nature to produce complex functional systems. They are precisely arranged at the nanoscale and they all work in harmony. This manufacturing method governs natural structures on all scales, from molecules to galaxies. Life processes have numerous examples involving the formation of nanostructures. The vast numbers of combinations occurred among atoms and molecules and materials obtained by these combinations. Life, itself, is assumed to be the end product of self-assembled hierarchical structures. Molecular machines such as ribosomes and light-harvesting photosystems and also the formation of the DNA double helix is made by self-assembly [6.39]. Molecular units assemble in specific patterns such as snow flakes, salt crystals. Molecular self-assembly-the spontaneous formation of molecules- has increasingly become a focus of non-biological research.

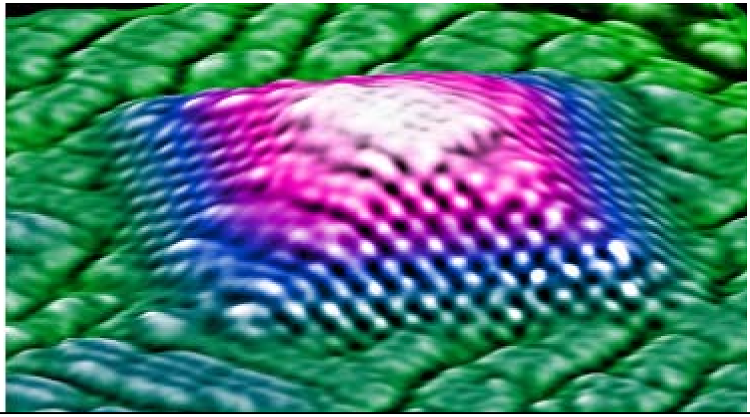


Fig.6.26: Image of quantum dot formed by self-assembling (Ge "pyramid")

Self-assembly is one of the few practical strategies for making ensembles of nanostructures, because of this it will be an essential part of nanotechnology [6.38]. The use of self assembly in industry is relatively new, and it is considered as a key technique in nanotechnology. Nanotechnologists are imitating self-assembly processes to make artificial novel structures that are not found in the natural world. The main idea behind in self-assembly process is that molecules always seek the lowest energy level available to them and this is achieved without guidance or management from an outside power. In self-assembly, the nano builder introduces particular atoms or molecules onto a surface or onto a pre-constructed nanostructure. The molecules arrange themselves into particular positions to minimize the total energy. This is materialized by forming weak bonds or by forming strong covalent ones [6.40].

Researchers are trying to create a new paradigm in mass manufacturing in which self-assembly replaces assembly of parts one by one. It is believed that this technique will one day allow the fabrication of materials and devices from the bottom up. Researchers are providing molecular and particle interactions and a new source for a great variety of new materials. Different criterion for selection suggests that there are a great variety of materials that may be obtained by making use of self-assembly. It is probably the most important of the nanoscale fabrication techniques because it has the ability to produce structures at different length scales with low cost [6.41]. Self-assembly offers huge economies, and promises great potential especially in nanoelectronics. However, it is not limited only to electronics applications. Self-assembled structures can be used also for protecting a surface against corrosion or making a surface slippery, stick, wet or dry [6.42]. The concept of self-assembly is used increasingly in many disciplines with a different flavor and emphasis in each [6.38].

A scanning tunnelling microscope (STM) image of a pyramid formed by self-assembly method in just a few seconds is shown in figure 6.26. The structure is formed by germanium atoms on top of a silicon surface. Round-looking objects in the image are actually individual germanium atoms. The pyramid is 10 nm across at the base, and it is actually only 1.5 nm tall [6.40] (for more examples see Appendix).

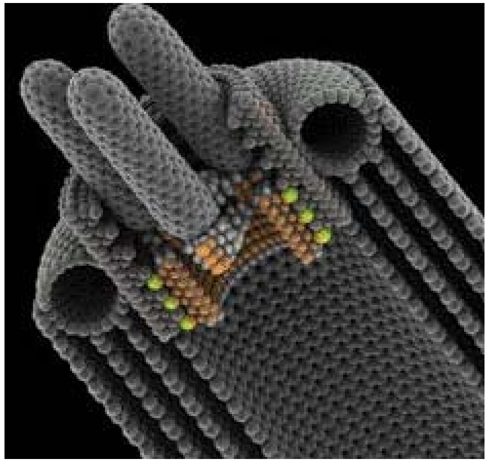


Fig.6.27: nBots created by Peter Yeadon are nanoscale robotic devices that rapidly self-assemble to form mass, machines, objects, and environments. Each is capable of securing itself to its neighbour.

Self assembly provides an evolutionary path to complexity and its inherent modularity means structures can be created, disassembled. This revolutionary manufacturing method opens new scientific frontiers and offers many opportunities. Growing machines may not be as far-fetched as it once seemed. The intent is to modify self-assembly to get materials to form more complex structures and to create a new paradigm in mass manufacturing in future [6.43].

Although the future of nanotechnology is largely a question mark, some fantastic forecasts have been already laid out. It is predicted that molecular manufacturing, nanorobotics, and nanobiotechnology will revolutionize society and its design disciplines [6.49].

Some futurists predict that the most profound changes will be the result of the molecular manipulation, where entirely new forms of life are being designed and created at the molecular and even sub-atomic level. This is where nanotechnology intersects with bioengineering, in a field known as nanobiotechnology. Nanobiotechnology makes it possible for virtually anyone to design and build virtually anything, using nanorobots [6.2].

Nanorobots will offer new opportunities for making mass from assemblies of tiny robots. A fully programmable environment could be possible where these assemblies can be commanded to change in form, color, texture, density, and viscosity, and can communicate with each other and us. Nanobiotechnology might facilitate the integration of living systems and inanimate matter and devices. Yeadon P. considers that it might be possible to create a form of living architecture by erasing the distinction between natural and artificial [6.46].

Utility fog is the most known nanobot conceived by nanotechnologist Dr. J. Storrs Hall. It is a hypothetical collection of tiny self-replicating robots. Each utility fog consists of individual units, called Foglets. Those foglets can be imagined as microscopic robots that can take the shape of virtually anything.

"Imagine a microscopic robot. It has a body about the size of a human cell and 12 arms sticking out in all directions. A bucketful of such robots might form a 'robot

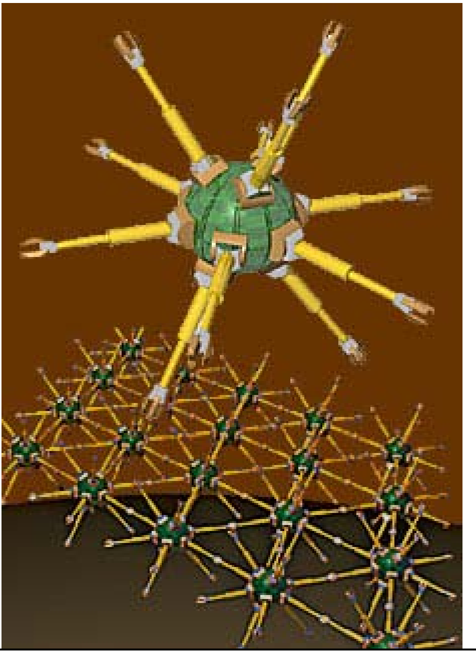


Fig.6.28: This Utility Fog material, composed of individual foglets.

crystal' by linking their arms up into a lattice structure. Now take a room, with people, furniture, and other objects in it -- it's still mostly empty air. Fill the air completely full of robots. The robots are called Foglets and the substance they form is Utility Fog, which may have many useful medical applications. And when a number of utility foglets hold hands with their neighbors, they form a reconfigurable array of 'smart matter.'" Dr. J. Storrs Hall [6.47]

As understood from above Dr. Hall has proposed that many of these foglets can be joined together to form intelligent polymorphic forms. Using nanotechnology, fully intelligent polymorphic material can be designed. They consist of trillions of microscopic machines and form a structural substance that can be programmed and change shape on command. Arms would grasp other foglet arms for building up mass, but also as a conduit for power and communication connectivity [6.48].

On the other hand, new technologies are often met with doubt and criticism. Some other futurists predict that nanotechnology may get out of control, causing a huge man-made disaster. Eric Drexler and others take into consideration that self-replicating machines might run amok if they escape into the environment, competing with natural bacteria, plants, and people for natural resources. This technology will open both a huge range of opportunities for benefit and a huge range of opportunities for misuse.

CONCLUSION

Architecture is affected by the thrust of technology through history. This impact has been largely evolutionary and this evolutionary process is occurred from simple construction methods, based on local resources to an increasing use of commercially produced building components. The technological development of architecture has been dependent on discoveries surrounding the best capacities of each material. With the growth of science and technology, broad material benefits were achieved.

Through the history scientific revolutions have transformed the methods and meaning of design and architecture. Nanotechnology presumed to be the Industrial Revolution of the 21st century because it promises a driver of change in the future by the understanding of materials and controlling their structure at the nanoscale. It would be as influential in the 21st century as digital revolution was in the 20th century. It opens the way towards new production routes, towards new, more efficient and intelligent materials. A series of new breakthroughs with new materials, devices and services can be created which can directly impact architecture. By using this technology, materials that are used in construction industry could be enhanced. Harder, stronger, more reliable, and safer materials can be produced so that they last many times longer than our current technology.

However, like any technology, the viability of nanotechnology depends on its industrialization and commercialization. There are plenty of ongoing researches that need more testing, time and investment for the commercial production.

In the last decade the number of nano-related patents increased enormously. It is expected that in the near future, nanotechnology will offer architecture an abundance of smart materials which will be precisely engineered to perform specific tasks. Various products such as self cleaning materials, nano-sensors, nano-solar-cells and many others would be inevitable design elements at the near future. For the future of tall buildings, which is presented as a case building type, it can be expected that more innovative tall buildings will be built with the aid of nanotechnology. With these completely new materials and components more durable, efficient, cost-effective and superior buildings can be realized. The need to conserve global material and energy resources requires more energy-efficient buildings. The significance of improving the buildings' environmental sustainability considered as urgent and the use of renewable sources with advanced technological solutions predicted as a future design solution. Architecture should respond to technological and environmental concerns. Buildings of the 21st century should be responsive to environmental conditions to embrace sustainable development. Energy conscious design is one of the responsibilities of the architects requiring an understanding of the fundamental materials and devices. Nanotechnology has the potential to offer efficient solutions for the sustainable design. Beyond the rapid growth of new smart materials and products molecular manufacturing, nanorobotics, and nanobiotechnology might be revolutionize the design disciplines and the society

Nanotechnology is a multidisciplinary field that includes materials science and engineering, mathematics, physics, biology, chemistry, computer science, and many other scientific areas. A common work between various disciplines will play a key role to achieve the maximum benefit from this new technology. Architects must be aware of new technologies to create more innovative and efficient solutions. It is significant, understanding the fundamental principles of architecture-related disciplines. A dialogue is needed across the professionals to understand the nanotechnology's full impact on architecture and built environment

Appendix I
Rules of Six

Architects Aranda/Lasch created ‘Rules of Six’ (the large wall relief) project for the “Design and the Elastic Mind” expo at MOMA, New York. The project explores self-assembly and modularity across scales. They envision an unpredictable, self-generating landscape of interlocking hexagons. These could represent rooms, buildings or entire urban neighborhoods. They create a sprawling matrix of three-dimensional structures which can multiply indefinitely without sacrificing stability. They use Rhino3D, high-density foam and an algorithm that mimicks the growth patterns of microscopic structures, [A.1].

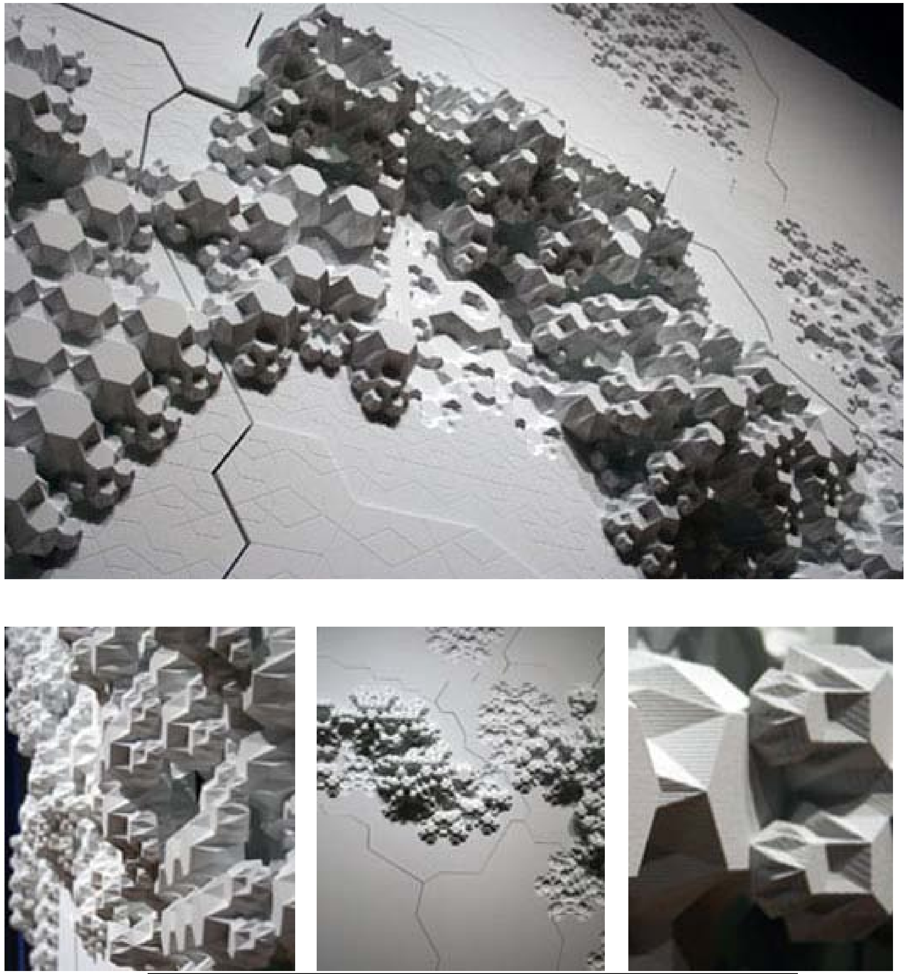
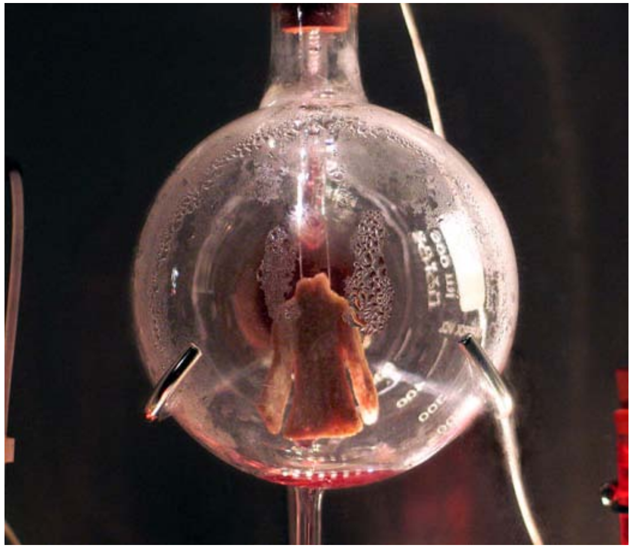


Fig.A.1: “Rules of Six” by Architects Aranda/Lasch



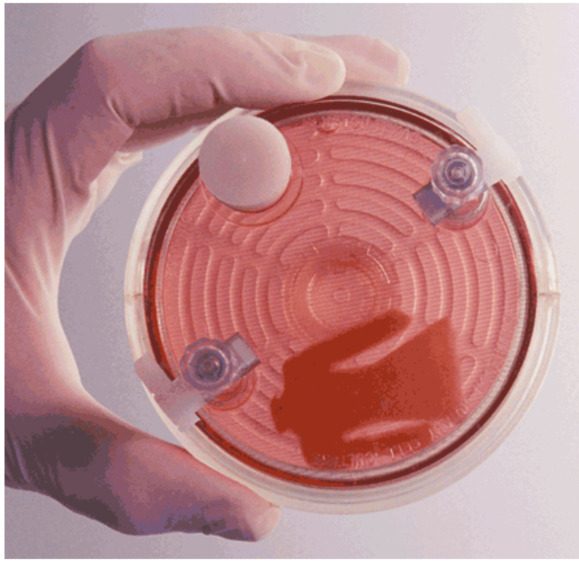


Fig.A.2: Victimless Leather

Appendix II
Victimless Leather

New technologies have been recently addressed and explored through art. The Victimless Leather, the Tissue Culture & Art (TC&A) Project concerns with growing living tissue into leather like material. Artists Oron Catts and Ionat Zurr, from the University of Western Australia's Art and Science Collaborative Research Laboratory-Symbiotica, have formed three tiny jackets by growing a mouse cell-culture over a polymer mould. It is grown out of immortalised cell lines which cultured and form a living layer of tissue supported by a biodegradable polymer matrix in a form of miniature coat like shape. They hope to apply tissue engineering techniques to create futuristic objects which are partly artificially constructed and partly grown/born. Catts says:
"*We see our role as artists as one in which we are providing tangible example of possible futures, and research the potential affects of these new forms on our cultural perceptions of life*." [A.2]

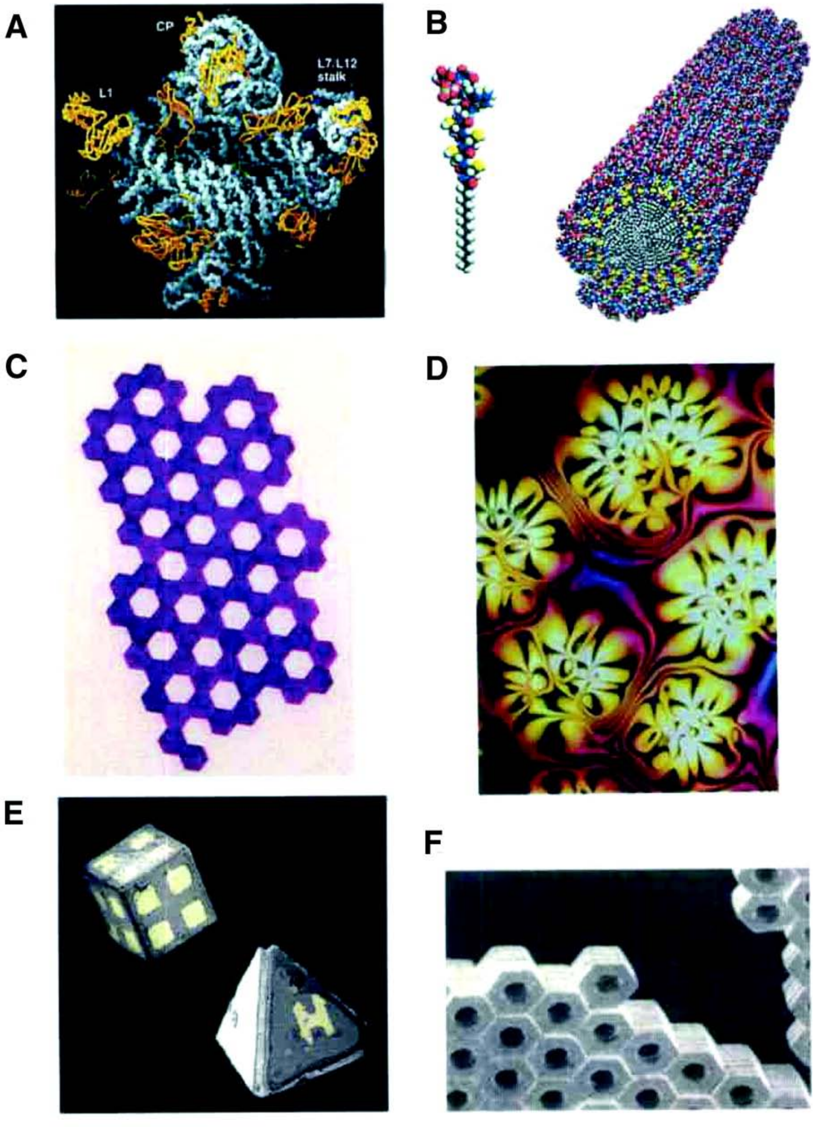


Fig.A.3: Examples of Static Self-Assembly

Appendix III

Examples of Static Self-Assembly

Static self-assembly involves systems that are at global or local equilibrium and do not dissipate energy. In static self-assembly, formation of the ordered structure may require energy, but once it is formed, it is stable. Most research in self-assembly has focused on this static type.

(A) Crystal structure of a ribosome.

(B) Self-assembled peptide-amphiphile nanofibers.

(C)An array of millimeter-sized polymeric plates assembled at a water/perfluorodecalin interface by capillary interactions.

(D) Thin film of a nematic liquid crystal on an isotropic substrate.

(E) Micrometer-sized metallic polyhedra folded from planar substrates.

(F) A three-dimensional aggregate of micrometer plates assembled by capillary forces [6.45]

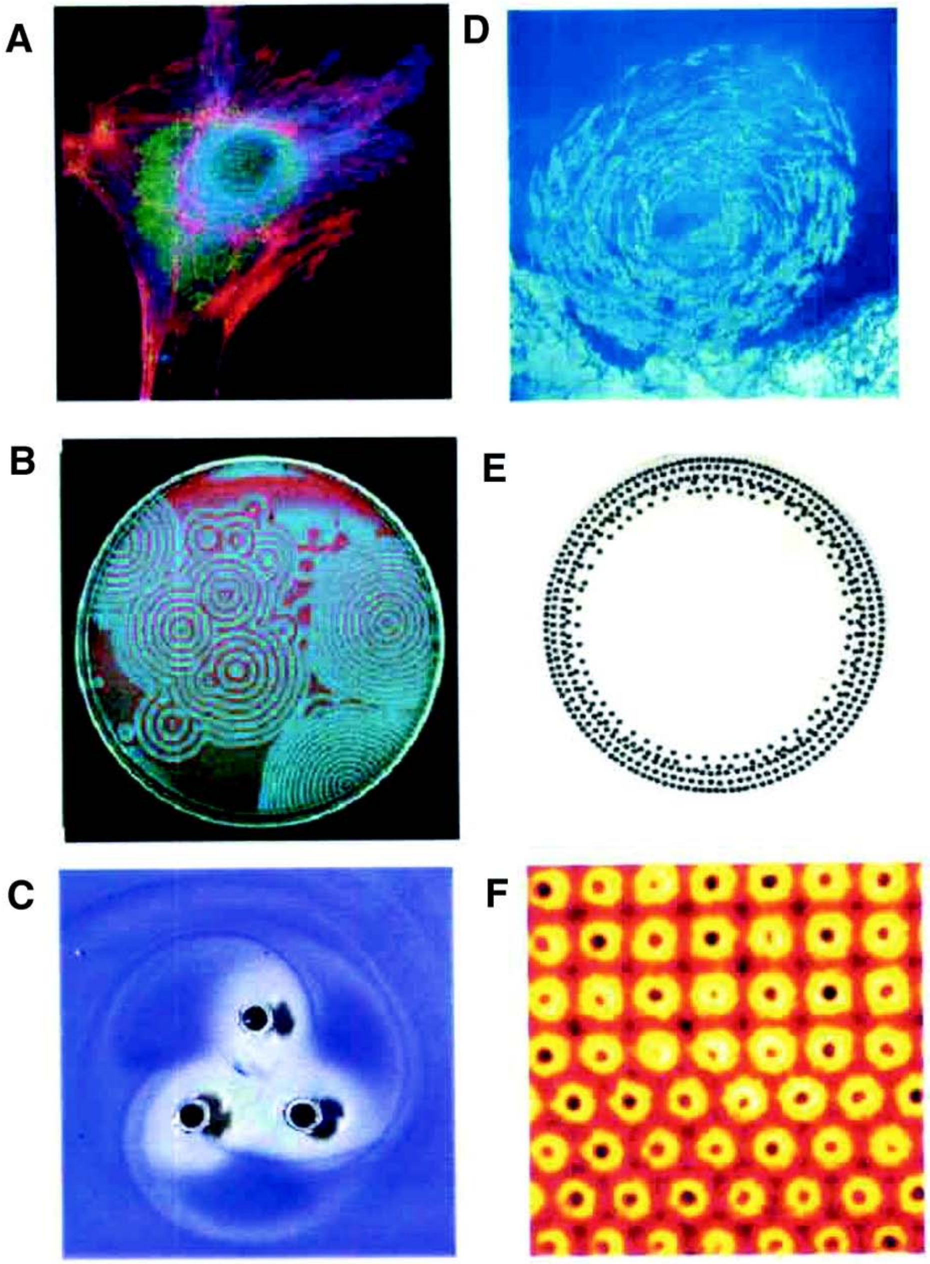


Fig.A.4: Examples of Dynamic Self-Assembly

Appendix IV
Examples of Dynamic Self-Assembly

In dynamic self-assembly, the interactions between components can only occur if the system is dissipating energy. Thus, the formation of structures or patterns can be achieved. The patterns formed by competition between reaction and diffusion in oscillating chemical reactions are simple examples; biological cells are much more complex ones. The study of dynamic self-assembly is in its infancy.

(A) An optical micrograph of a cell with fluorescently labeled cytoskeleton and nucleus; microtubules (~24 nm in diameter) are colored red.
(B) Reaction-diffusion waves in a Belousov-Zabatinski reaction in a 3.5-inch Petri dish.
(C) A simple aggregate of three millimeter-sized, rotating, magnetized disks interacting with one another via vortex-vortex interactions.
(D) A school of fish.
(E) Concentric rings formed by charged metallic beads 1 mm in diameter rolling in circular paths on a dielectric support.
(F) Convection cells formed above a micropatterned metallic support. The distance between the centers of the cells is ~2 mm.[6.45]

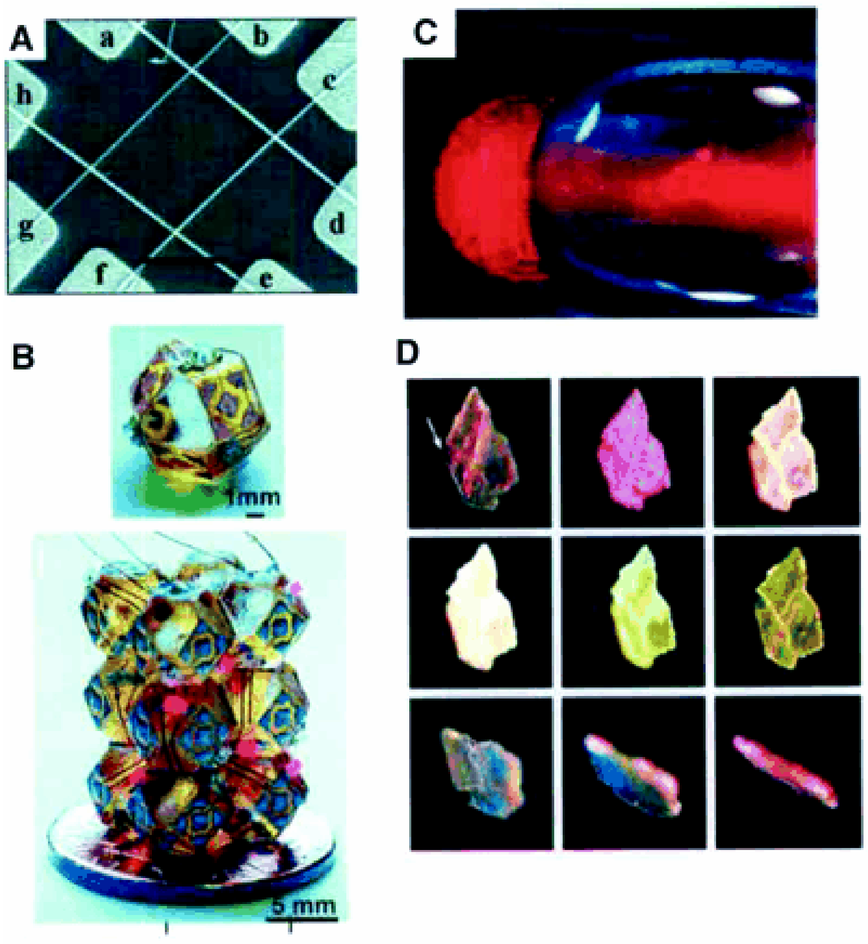


Fig.A.5: Examples Of Self-Assembly

Appendix V
Examples Of Self-Assembly

A) A 2 by 2 cross array made by sequential assembly of n-type InP nanowires with orthogonal flows.
(B) Diffraction grating formed on the surface of a poly(dimethylsiloxane) sphere ~1 mm in diameter. The sphere was compressed between two glass slides, and its free surface was exposed to oxygen plasma. Upon release of compression, the oxidized surface of the polymer buckled with a uniform wavelength of ~20 µm.
(C) Three-dimensional electronic circuits self-assembled from millimeter-sized polyhedra with electronic components (LEDs) embossed on their faces.
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