ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

POSSIBLE FUTURES FOR ARCHITECTURAL ENTITY WITHIN THE CONTEXT OF TRANSDISCIPLINARY TECHNOLOGICAL DEVELOPMENTS

M.Sc. Thesis by
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Department : Informatics

Programme : Architectural Design Computing

JANUARY 2009

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Date of submission : **29 December 2008**
Date of defence examination: **22 January 2009**

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JANUARY 2009

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

DİSİPLİNLER ÖTESİ TEKNOLOJİK GELİŞMELER BAĞLAMINDA MİMARİ VARLIĞIN OLASI GELECEĞİ

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Tezin Enstitüye Verildiği Tarih : **29 Aralık 2008**
Tezin Savunulduğu Tarih : **22 Ocak 2009**

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OCAK 2009

ACKNOWLEDGEMENTS

I would like to express my deep gratitude for my advisor Prof. Dr. Gülen Çağdaş who has supported my studies right from the first moment when I expressed my intent for doing a graduate study in Architectural Design Computing Program in ITU till the completion of this thesis.

I would like to thank my co-supervisor Dr. M.Tanyel Türkaslan Bülbül for her support in the development of this thesis.

I would also like to express my deep appreciation to my dear mother Bingül Başarır and to my dear father and colleague Öztürk Başarır for their anything and everything.

I would like to thank Assoc. Prof. Dr. Arzu Erdem and Assoc. Prof. Dr. Birgül Çolakoğlu for their insightful and constructive contribution to my thesis as members of the examining committee.

I would like to thank Dr. Doğan Hasol very much for his moral support for my graduate study at ITU.

Finally, I would like to express my deep gratitude for, the great person whom I owe my freedom of education in this beautiful country, Mustafa Kemal Atatürk for sharing his guidance.

January 2009 Lâle Başarır

Architect

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ABBREVIATIONS

AI	**:** Artificial Intelligence
App	**:** Appendix
CATIA	**:** Computer Aided Three-Dimensional Interactive Application
CNC	**:** Computer Numerically Controlled
CRAFT	**:** Center for Rapid Automated Fabrication Technologies
ITU	**:** Istanbul Technical University
MM	**:** Molecular Manufacturing
MMPOG	: Massive Multi-Player Online Games
NSA	**:** Non-Standard Architecture
RM	**:** Rapid Manufacturing
RP	**:** Rapid Prototyping
SLA	**:** Stereo Lithography Apparatus
SLS	**:** Selective Laser Sintering
STM	**:** Scanning Tunneling Microscope
VBA	**:** Visual Basic for Applications
2D	**:** 2 Dimensional
3D	**:** 3 Dimensional

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POSSIBLE FUTURES for ARCHITECTURAL ENTITY WITHIN THE CONTEXT of TRANSDISCIPLINARY TECHNOLOGICAL DEVELOPMENTS

SUMMARY

Rapid pace of recent technological developments play a very constructive role on the way humans relate to their environments. The objective of this research study is to make a forecast of what architecture may evolve into within the context of transdisciplinary technological developments. The possibilities are analyzed within the intersection of four major disciplines: Nanotechnology, Robotics, Artificial Intelligence (AI) and Genetics. These disciplines are analysed in terms of new technological innovations they generate and new paradigmal promises they hold for architecture. Nevertheless, the main focus is on nanotechnology, and the possible paradigm shifts it might cause in architecture in a few decades. Thus, Genetics is the area in which Nature's own technology of data storage for cellular fabrication is analysed, and Robotics, bonded very tightly with AI, feed the subject fundamentally in terms of how a new model for the automation of architectural production is envisioned.

Contemporary architectural creation has mainly been in connection with materials and advancements in manufacturing and construction technologies. Hardware capabilities in terms of material and construction have formed the way spatial boundaries were designed. Close relationship of architectural practice with materials and construction techniques is analyzed.

The Industrial Revolution was about new manufacturing technologies and a whole new way of living that it brought about. The digital revolution, at the beginning of information age, was mainly about computing. Therefore, it caused a shift from hardware (matter) to software (idea) in many terms. There is a seemingly cyclical transformation of revolutionary developments in information and manufacturing. The cycle now looks as if the next revolution will be about digital fabrication and miniturization. Literally, digitization provided conversion of atoms to bits and apparently, it is time for converting bits to atoms, in a new manner.

Representation of ideas has been a major issue for design and construction. Blueprints had been the documents of communication. This representation, though, has not always been sufficient in terms of communicating novel and complex

designs. Therefore, difficulties in communicating design intent to other parties in charge of construction caused all parties to resign from taking bold steps. Information technology, its impact on architecture and the cyclical conversion between idea and matter is analyzed in chapter two.

As soon as design representation came to a point where each complex detail could be communicated through information processing, customization possibilities fluorished in building design. Mass-Customization was not achieved only through information technologies but also through manufacturing technologies that have developed simultaneously. These manufacturing technologies were the outcomes of robotic technologies. Although robotics is a major discipline creating its own technologies, robotic capabilities are embedded in every automated manufacturing and construction technology. Robotics is integrated in the manufacturing of parts, in on-site operations and in buildings once they are fully operational. Besides, artificial intelligence, added greater automation possibilities to the expertise of robotics. So artificial intelligence is another path to walk through in an endeavor to visualize ways of future architectural execution. Greater automation possibilities require greater control and perfection in manufacturing. Nanotechnology, currently, leads the closest way to this type of perfection. Manipulating matter at atomic and sub-atomic scales can be defined as what nanotecnology refers to. In chapter three, means of automation and molecular manufacturing possibilities are analyzed.

Deriving from current developments and growing hardware (matter) and software (idea) capabilities, a forecast is made on how future buildings will be. The forecast in concern is quite fictive although derived from facts. Furthermore, information as a whole is expanding so rapidly that it is very probable that future holds greater surprises than the past. Science is uncovering many facts about the universe that we live in. Simultaneously, science is discovering new mysteries to uncover thereby causing paradigm shifts. Currently, quantum theory is reaching a level where it is on the verge of creating unprecedented speeds in computation, data processing and retrieval. This development encourages alternate ways of thinking. The thesis offers a fictive approach for architecture along with other suggestions from some pioneers of physics and architecture. Utility Fog is a fictive definition of a fog of tiny intelligent matter at molecular scale called Foglets which has the ability to take on new densities, new forms and functions due to new programming. These issues bind the final chapter thereby introducing immortality as a notion for buildings as architectural products.

DİSİPLİNLER ÖTESİ TEKNOLOJİK GELİŞMELER BAĞLAMINDA MİMARİ VARLIĞIN OLASI GELECEĞİ

ÖZET

Yakın zamanda teknolojilerde meydana gelen hızlı gelişmeler insanların çevreleriyle kurdukları ilişkide önemli ve şekillendirici bir rol oynamaktadır. Bu tez çalışmasının amacı disiplinler ötesi teknolojik gelişmeler bağlamında mimarlığın nasıl bir evrim geçireceği üzerine tahminler oluşturmaktır. Olasılıklar, dört ana disiplin olarak Nanoteknoloji, Robotik, Yapay zeka ve Genetik alanlarının kesişim bölgesinde incelenmektedir. Bu disiplinler, mimarlık için yarattıkları teknolojik yenilikler ve sunabilecekleri olası modeller açısından incelenmektedirler. Bununla birlikte tezin odak noktası nanoteknoloji ve bu teknolojinin orta vadede mimarlık için yaratabileceği olası modellerin incelenmesidir. Benzer şekilde, Genetik doğanın hücresel üretim için kullandığı veri depolama teknolojisi açısından incelenmektedir. Robotik alanı ise Yapay zeka ile içiçe geçmiş olarak mimari üretimde otomasyon için yeni bir modelin nasıl oluşturulabileceği ile ilgili konuyu temel olarak beslemektedir.

Çağdaş mimari yaratım süreçleri çoğunlukla malzemeyle ve üretim ve inşaat teknolojilerindeki gelişmelerle bağlantılı olarak gelişti. Mekansal sınırların tasarımını malzeme ve inşaat anlamında sahip olunan donanımsal kapasite şekillendirdi. İkinci bölümde, mimarlık pratiğinin malzeme ve inşaat teknikleriyle yakın ilişkisi incelenmektedir.

Endüstri Devrimi, yeni imalat teknolojileri ve bunun getirdiği bütün bir yeni yaşam biçimini içermekteydi. Bilgi çagının başında meydana gelen sayısal devrim ise esas olarak bilgi işleme teknolojilerini içermekteydi. Böylelikle donanımdan (madde) yazılıma (fikir/bilgi) bir geçişe sebep oldu. Bir inceleme yapıldığında bilgi ve imalat alanlarında birbirini izleyen devrimsel gelişmeler bir dönüşüm çemberi görüntüsü vermektedir. Çember, şimdi de bir sonraki devrimin sayısal tabanlı imalat ve küçültme/minyatürleştirme ile ilgili olacağı yönünde bir görünüm sergilemektedir. Sayısallaşma, tam anlamıyla atomlardan bilgi iletme birimlerine (bit) dönüşümü sağladı ve görünen o ki sıra bitlerden atomlara dönüşüme geldi.

Fikrin temsili, tasarım ve inşaat için her zaman önemli bir konu oldu. Uygulama projeleri iletişim belgeleri olarak kullanıldı. Ancak bu temsil şekli yeni ve karmaşık

tasarımlar için her zaman yeterli olamadı. Bu nedenle tasarımın inşaasından sorumlu taraflara aktarılmasında yaşanan zorluklar cesur adımlar atılmasını çoğu zaman önledi. Bilgi teknolojileri, bu teknolojilerin mimari üzerinde oluşturduğu etki ve madde ile bilgi arasındaki dönüşüm çemberi ikinci bölümde ele alınmaktadır.

Bilgi işleme imkanları aracılığıyla tasarımın temsili karmaşık detaylarının iletilebildiği bir duruma gelir gelmez bina tasarımında özelleştirme (customization) olanakları da gelişti. Seri/Çoklu-Özelleştirme (Mass-Customization) yalnızca bilgi teknolojileri sayesinde değil aynı zamanda gelişen üretim teknolojilerinin de katkısıyla başarıldı. Bu üretim teknolojileri robotik teknolojilerinin ürünleriydi. Robotik, başlıbaşına bir bilim alanı olmakla birlikte üretim ve inşaat alanındaki tüm otomatikleşme süreçlerinde robotik kapasite bulunmaktadır. Robotik, yapı elemanlarının üretiminde, inşaat süreçlerinde ve daha sonra da yapının kullanımı sürecinde yer almaktadır. Bunun yanında yapay zeka da robotiğin uzmanlık alanına daha güçlü bir otomasyon kapasitesi ekledi. Bu nedenle yapay zeka, gelecek mimari üretimlere dair görüş geliştirirken benimsenen ek bir yol oldu.

Daha geniş otomasyon olanakları üretimde daha geniş kontrol ve mükemmeliyet gerektirmektedir. Nanoteknoloji, bu tür bir mükemmeliyet için en güncel ve yakın yolu göstermektedir. Maddenin atom ve atom-altı ölçeklerde işlenmesi, nanoteknolojinin kapsamını tanımlamaktadır. Üçüncü bölümde otomasyon unsurları ve zerre ölçeğinde üretim olasılıkları incelenmektedir.

Güncel gelişmeler ve gelişen donanım (madde) ve yazılım (fikir/bilgi) kapasiteleri ışığında geleceğin binalarının nasıl olacağına dair tahmin yapılmaktadır. Sözü edilen tahmin gerçeklerden yola çıkmakla birlikte kurgusal bir tahmindir. Ayrıca, bir bütün olarak bilgi o derece hızlı gelişmekte ve büyümektedir ki geleceğin sürprizlerinin geçmişe kıyasla çok daha büyük olması çok olasıdır. Bilim, içinde bulunduğumuz evrene dair pek çok gerçeği açığa çıkarmaktadır. Aynı zamanda bilim açığa çıkarılacak yeni gizemler de keşfetmekte ve yeni bakış açılarına yol açmaktadır. Bugün, kuantum teorisi bilgi işlemede görülmemiş hızlara ulaşmayı sağlayacak bir düzeye erişmek üzeredir. Bu gelişme, alternatif düşünme biçimlerini teşvik etmektedir. Bu tez, fizik ve mimarlık alanlarında öncü bazı kişilerinin çalışmalarının yanısıra mimariye kurgusal bir yaklaşım önermektedir. Fayda Sisi (Utility Fog) “Foglet” adı verilen, yeni programlamalara göre yeni işlev, kıvam ve form alan moleküler ölçekte küçük ve akıllı maddelerden oluşan bir sis bulutu için kullanılan kurgusal bir tanımlamadır. Bu konu mimari ürün olarak binalara ölümsüzlük kavramını içeren bir önermeyle son bölümü tamamlamaktadır.

1. INTRODUCTION

What “Architecture” might evolve into in the future, is an issue that requires sorting out the basic principles of the profession. Architecture, as its very core meaning implies, is the art and science of design and structure. There had been many thoughts put into the description of architecture and of fine architecture throughout the history. Therefore, *basics* have provided discrete foundation for many new and revolutionary aproaches to seed and flourish in the field of architecture. Earliest description of fine architectural object as being “durable”, “utilitarian/convenient” and “beautiful” have created somewhat a repetitive cycle in terms of architectural style and ways of living (Vitruvius, 25BC,1914). Therefore, Architecture has introduced various structures that have surpassed being solely the art and science of sheltering. It integrated forms, techniques, approaches and strategies from all sorts of fields concerning “life of humans”. Along with those integration many influences have been made by economy, wars, politics, artistic transformations, changing lifestyles, scientific discoveries and inventions. However, the evolution of architecture could be followed on the same path which led manufacturing and construction technologies towards progress. This was because architecture itself has been involved with material reality in a Newtonian universe. Therefore, the history has it that visions have always outdated reality.

1.1 Threshold Definition

Contemporary architectural design has rooted on new materials, novel technologies and new manufacturing and construction processes, and so did the whole architectural output throughout the history. Given the fact that most revolutionary changes in architecture have been due to hardware capabilities of construction technologies, we may well predict that architecture is on the verge of a new revolution just by looking at the pace of technological developments, today. These technological developments are defined in the following chapters.

The core issue of this study addresses new possibilities of automation systems and advancements in materials science and manufacturing methods for architectural construction. These advancements are analyzed through technological developments in other areas of manufacturing as well as architectural fabrication. Therefore, the research includes how new technologies can theoretically and at times practically be adapted to building architecture, thereby projecting new architectural approaches inspired from explorations on molecular manufacturing. Molecular manufacturing (MM) is generally described as a precise structural manipulation of matter at molecular scale at very low prices and directly from digital information (bits) and specific source materials.

1.2 Objectives

The objective of this thesis is to make a forecast of what architecture may evolve into within the context of interdisciplinary technological developments. The possibilities are analyzed within the intersection of four major disciplines: Nanotechnology, Robotics, Artificial Intelligence (AI) and Genetics. These disciplines are analyzed in terms of new technological innovations they generate and new paradigmal promises they hold for architecture. Nevertheless, the main focus is on nanotechnology, and the possible paradigm shifts it might cause in architecture in a few decades. Therefore, Genetics is the area in which Nature's own technology of data storage for cellular fabrication is analyzed, and Robotics, bonded very tightly with AI, feeds the subject fundamentally in terms of how a new model for an autonomous architectural production may be envisioned.

1.3 Limits

As mentioned earlier, there had been many thoughts put into the description of fine architecture throughout the history. Therefore, it is not possible to discuss what "fine architecture" should be, within the scope of this thesis. The subject is absolutely extensive. Therefore, "fine architecture" in this context is defined as the most revolutionary structures which have been utilitarian, durable and somewhat beautiful precedents of richer architectures. Considering the fragility of the subject, the focus can be limited to how effective the construction capabilities have been on architectural productivity.

This limitation, however, does not exclude a new approach to architecture which craves for a wholistic perfection in all terms of durability, beauty and function. What's next in architecture might well be a new understanding of simultaneously customizable, magically transformable and intrinsically sensitive definitions of space full of surprise and freedom.

Symptoms of new definitions of space have been around for some time, by now. Most endeavors however, still have the nature of bringing hardbound-spaces (hardware) together with virtual nuances. Therefore, what might have been really revolutionary would be hybridizing all means of functions, beauty and structure in one process as it is in *growth.*

The thesis analyzes architectural entity starting from today's changing domain of architectural creation with a very short reminder of industrial progress made within the last two centuries. The future projection of the thesis reveals a vision of architectural space as a formation of architectural entity rather than an space constructed with brute force.

2. INFORMATION TECHNOLOGY AND ITS IMPACTS on ARCHITECTURE

Architecture had a static nature due to its functionality and the way it was produced. Likewise, many utilities that were embedded in our lifestyles have been encased in solid gadgets or spatial boundaries. Buildings, as complex structures have been rather cumbersome for any change once built. This is not only due to having solid boundaries such as walls. Those walls in concern have also been the bearers of infrastructure, or the structural system, in most cases.

2.1 The Architectural Object

All production of material substance which qualify as “real” have come to be accepted as subject to laws of a Newtonian universe. This hasn’t changed to date, for the scale of architectural execution. Indeed, architectural design, throughout its history has been solidified due to these laws. These laws affected how a structure would be built and how it stayed erect. Whichever novel design that didn’t come up with the answer to this famous question of how it was going to be built would be sentenced to life imprisonment in sketchbooks. This seems to be the reason why great architects had to be great constructors in order to execute their innovative masterwork. Thus, recently construction companies and contractors became more predominant than architects in the construction site. This situation also led to reduction of architects role on site in terms of controlling the output. However, this situation might change once the production methods improve at the same pace with developments in other technologies mentioned throughout this thesis.

The material connection of architecture had been quite plain until the Industrial Revolution. Materials were chosen either for their utility and availability or for their visual and their decorative qualities. Therefore, the scope of information on materials was due to experience and was acquired through convention, and trial-error cases. What the Industrial Revolution brought about was the notion of engineered materials.

With the wide spread introduction of steel in the 19th century, long-span and tall structures began to emerge. Materials adopted a new role of extending functional ability rather than the older subordinate role in architectural context. This shift enhanced formal boundaries (Sebestyen and Pollington, 2003).

Crystal Palace was built as the Great Exhibition building of 185. The palace was a hallmark of Industrial Revolution. The 564m long, 33m high and dwelling on a 92,000 m^2 area glasshouse consisted of pre-cast elements of wrought-iron and large spanning glass sheets. The palace was designed by a gardener building glasshouses for conservatory purposes. His expertise in conservatory design earned him recognition as an innovative architect (Url-1, 2008).

In 1887-1889, Gustave Eiffel, a steel construction expert, built a 300 meters high tower as a temporary exhibit for the '89 Paris World Exhibition. The building has not been taken down and has been a symbol of the growing steel industry along with other means. The tower was a fruit of new building capabilities provided by a, then the most sophisticated, material; steel.

At the time, there were many steel bridge structures being constructed in The United States and among the most notable ones was the Brooklyn Bridge designed by John A. Roebling. The Brooklyn Bridge was the first suspension bridge to use wire rope. Wire rope was a string structure made by twisting strands of wire around a core. This wire rope was used in all of the suspension bridges that Roeblings designed. However, these were the achievements of engineering. Without steel, those structures wouldn't be there. Similarly, reinforced concrete and industrialization of glass-making introduced unprecedented impact upon architectural execution. Architectural practice was freed from material limitations of masonry structures. However, the bold attempts of engineers and determination of employers played an equivalent role on the emergence of these structures.

Today, the definition of Material is also changing. Architectural experimentation is roaming at the limits of material and the immaterial properties of space. Material for architecture might be holding a new state of being rather than being some matter to be made out of. Hence, materials attain different properties than what they used to be in terms of appearance or function. A deceptive property is what materials are beginning to attain. An example of this is the Aerogel (Figure 2.1) that has a density of three times that of air but has considerable strength and insulation capabilities (Addington and Schodek, 2005). Aerogel is a solid but it is so transparent that it looks like a hologram (Url-2, 2008). Hardness is no longer a guarantying property for strength, or plastic is not so distinguishable from glass anymore.

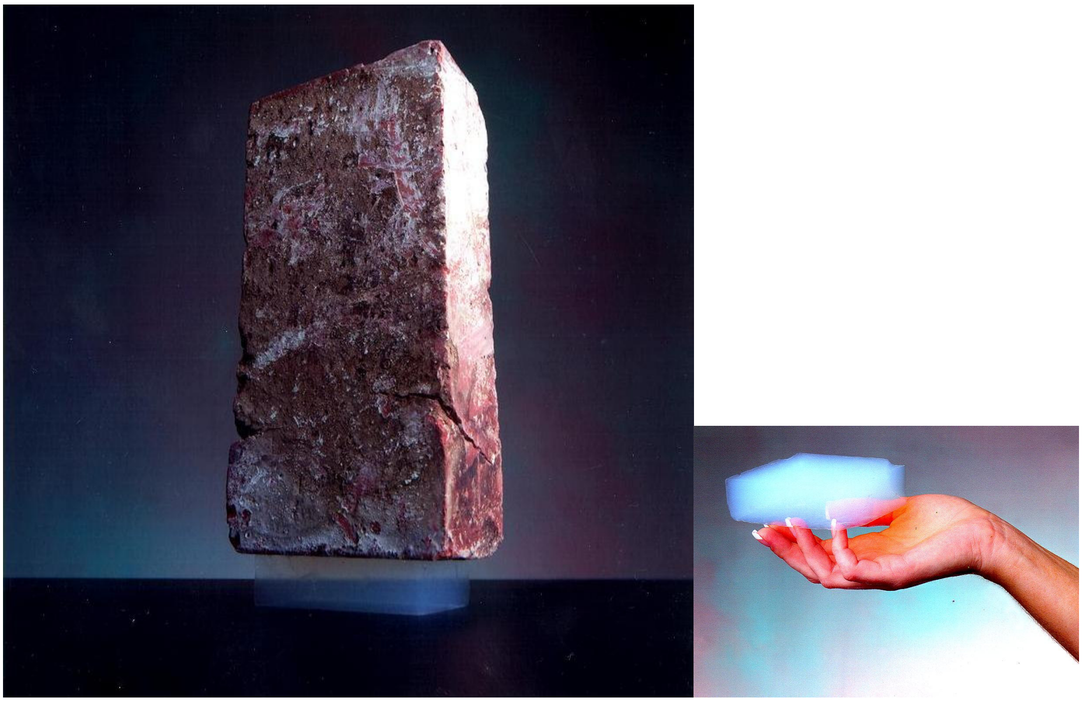

Figure 2.1 : A 2.5 kg brick is supported on top of a piece of aerogel weighing only 2 grams (Url-2, 2008)

The material connection of architectural execution has been quite intricate with constructional connection. Steel emerged as a material while proposing its own construction techniques, and so did concrete. Steel initially, had its nuts and bolts and welding technologies. Reinforced concrete was the technique created using the material properties of concrete and iron.

Many unprecedented wide-span structures fluorished as the result of new construction technologies (Sebestyen and Pollington, 2003). Therefore, due to the changing lifestyle following world wars and industrialization, new building types for transportation, manufacturing and commerce, became visible. To examplify new types, we can take the air traffic caused by increasing international and domestic connections. Thus, the effect of that air traffic resulted in major investments in air terminals. These buildings required new construcion technologies as well as new building and cladding materials. Therefore, new lifestyles and needs brought about novel structures, or superstructures. A well known example of a superstructure is the central hall of Lyon Airport Station in Lyon, France, designed by Santiago Calatrava, who is both an architect and an engineer. As technology improved the way the structural challenges were solved, there also appeared the flexibility of integrating movable parts into structures. Stadiums started being constructed with retractable roofs and other buildings with moving parts, emerged.

As the constructional capabilities grew as much to cope with complex designs integrating novel programs into building functions, it became harder to control costruction phases. However, through advancements in CAM/CAD technologies, design and construction of complex building programs became much more manageable.

The influence of technical progress in construction lead to the industrialization of construction which involved that structures and services integrated computers, new knowledge, mechanization, prefabrication and automation of construction into its process. Automation is also referred to as the appearance of robotics in construction (Sebestyen and Pollington, 2003). Therefore, the automation of fabrication and computerization of manufacturing parts has also created examples of the constructional connection we have seeked for. The manufacturing automation in concern was exemplified by some pioneers of architecture in their extraordinary building architectures.

In the case of automation in construction with computerized manufacturing, the industrialization in concern does no longer consist of linear mass production principles. Rather, it creates an opportunity for mass-customization thereby eliminating several phases that architectural design needs to go through before construction. This computerized automation in producing construction parts has been used in some striking building architectures either in the production of cladding or parts of structural systems.

2.2 Idea to Matter, Matter to Idea: A Constant Cycle of Idea and Matter

Throughout the history, we may find examples of knowledge and skills improving devices and in return, devices improving knowledge and skills. A very neat example of this cycle is the phenomenon of the printing press. The innovative movable type system revolutionized the act of printing which was then a slow and expensive process. Printing press converted knowledge to information that could be manufactured. Therefore, the end products were books and, in return, this hardware led to blooming of shared knowledge. As a result, the fusion of knowledge led to the Renaissance in Europe.

The Industrial Revolution was about manufacturing. Therefore, the digital revolution, at the beginning of information age, was mainly about computing. The Digital Revolution altered what we then knew about converting and translating visions, sounds, tactile properties etc. Likewise, some physical gestures such as pushing buttons were converted to software gestures like clicking on virtual interfaces. The conversion in concern was somewhat a shift from matter (hardware) into idea (software), thus into digits and 2-Dimensional (2D) or 3-Dimensional (3D) interfaces.

2.2.1 From hardware to software- Intelligence yields to shrinkage

Some gadgets have already become part of our nostalgia one by one as hardware dissolves into software. The once very precious pieces of our daily lives such as music player sets with tape recorders and synthesisers and LP players have become vaguely surviving old concepts. Similarly, music tapes of the days from two decades ago are no longer needed. These visible changes in our daily lives have been attributed mostly to the digital revolution which came after the industrial revolution but in a more exponential pace.

As software developments went further, new and enhanced electronics started outperforming older versions very rapidly. This was due to the inverse ratio between intelligence and dimensions. The intelligence in mention is not solely information but the capability of embedding software (idea) into hardware (matter). As a result of shrinkage, newer gadgets started substituting several gadgets with different functions, thus converging various devices in one (Url-3, 2008).

Nowadays, computer technologies are embedded in all design and production processes and design is created digitally in most practices. This brought a great advantage of bridging 2D layouts representing 3D information with production information and thereby, creating a wholesome where the smallest bit of a design would be considered as information carrying the awareness of the whole system. This awareness was due to being linked with embedded intelligence. Furthermore, embedded intelligence created smaller but smarter entities using the advantage of miniturization.

The shift from hardware to software in architecture is mostly realized in cyberspace applications. Virtual reality is a term coined by Jaron Lanier. He described virtual realty as an integrated computer-based sytem with both means of software and hardware in order to create an immersible 3D simulated environment (Bell, 2001). Virtual spaces are extending their application in the aspect of shrinking and simulating real spaces. Though not yet very fundamental, shifting from real to virtual spaces created new paradigms. Commercial applications like e-commerce, virtual worlds and 3D web malls can be considered as applications of real spaces dissolving into virtual spaces. Most widely accessible virtual worlds started as media for Massive Multi-Player Online Games (MMPOG) and some shifted from classical computer games to alternative social lives in cyberspace.

There are many developments in other disciplines affecting ways of execution within the profession of architecture. Throughout the history, avant-garde architects envisioned experimental spaces under the influence of developments and ideas adopted from other domains. This envisioning has sometimes been executed in forms of architectural drawings, models or in the form of literature. A simple example of forecasting some of todays digital/virtual architectural applications from back in 1995 is by W.J.Mitchell. He mentions how computational devices and sensors would be embedded in the spaces of our daily lives and how the profession of architecture will take on new concerns while leaving out some of the old concerns:

> *"...In the end, buildings will become computer interfaces and computer interfaces will become buildings.*
>
> *Architects of the twenty-first century will still shape, arrange and connect spaces (both real and virtual) to satisfy human needs...Firmness will entail not only the physical integrity of structural systems but also the logical integrity of computer systems. And delight? Delight will have unimagined new dimensions..." (Mitchell, 1995)*

Influences of new technologies can be traced back to the first quarter of the twentieth century in the experimental works of architects (Brayer, Migayrou, and Fumio, 2005). The visions set forth by them might not have been realized yet, however their visionary practice lead a brilliant way to emergent new architectures of their times and of today's.

2.2.2 From Software to Hardware

The advancements in computer technologies, as mentioned earlier, created new possibilities in fabrication and construction methods. Automated fabrication methods appear to hold greater promises in terms of social impact than automated computation, i.e. computers.

Currently, there is a seemingly cyclic transformation of revolutionary developments in information and manufacturing. The cycle now seems to be pointing out that the next revolution is going to be about digital fabrication and molecular manufacturing with all means of miniturizing. The digital revolution found ways of converting atoms to bits and apparently, it is time for converting bits to atoms but, in a new manner.

Marshall Burns, makes a comparison of automated fabrication and automated computation in terms of their impact:

"…The introduction and growth of computers have been heralded by some to indicate the dawn of a new era of human history, the so-called "information age." This idea supposes that the greatest value in our society is now placed on information and the tools and skills for storing and manipulating it. But it is possible that the information age will be short-lived, soon to be superseded by a new age in which man acquires untold powers to manipulate the properties of matter in much the same way that computers manipulate information..." (Burns, 1993)

The social impact of automated digital fabrication may be envisioned briefly with a scenario in which future customers click on their preferences from computer simulations of goods instead of their non-customizable mass-produced alternatives. Designs that are purchased are then run digitally on personal fabricators. Personal fabricators would be devices for desktop fabrication like printers in desktop publishing. Thus, the commercial product in this scenario becomes not the fabricated goods but the information needed to fabricate the goods. Therefore, the scenario depicts the way software is converted to hardware, this time (Burns, 1993).

Initial examples of converting bits to atoms are Computer Numerical Control (CNC) router machines. CNC machines have robotic arms that mill parts out of material blocks in a much more precise way that the human hand would do. However, the process in CNC machines are subtractive, whereas the conversion of bits into atoms would require additive processes.

Bits being converted to atoms implies many components and more than one discipline to come together. The thesis is more focused on molecular manufacturing (MM) techniques in terms of converting bits to atoms. However, macro-scale techniques are analyzed primarily in order to illustrate current technologies. Macro-scale manufacturing thechniques other than CNC involve rapid prototyping and rapid manufacturing machines that are a subgroup of 3D printing techniques. These techniques are explored in the next chapter.

2.3 Building as an Information System

Buildings and molecular manufacturing may seem too far from being relevant. However, architectural design has been an information system right from the beginning as it was the informative representation of architect's ideas. Thus, through computation, architectural design representation evolved into a very sophisticated information system. Therefore, before molecular manufacturing takes place, there has been and will be phases of this evolution in concern. What has happened is generally called a greater automation. In other words, the digital revolution converted design to an organised whole of information which can be retrieved at any time and be reorganised instantly. This development transformed the interaction of design input with production/construction output. The transformation in concern spans from customized manufacturing as in *file-to-factory* applications to higher speeds of communication and error correction.

Since the Industrial Revolution architects and contractors have had different directions which generally led them to having conflicting approaches. Those conflicting perspectives at times lowered the quality of architectural execution and innovation in buildings.

Digitization of design created the opportunity of simultaneous consultation from members of a team gathered to elevate buildings; a team of designers, engineers, manufacturers and constructors. The architecture firm SOM (Skidmore, Owings & Merrill LLP) was among the earliest adopters of computation in architectural practice. They are known to have utilized the concepts of Building Information Modeling (BIM) concept in the 1970s and 80s (Bordenaro, 2007).

Design representation had been a major issue for design and construction. Blueprints had been treated as legal documents and were always handy for the lifetime of buildings. However, technical drawings have been 2D representations of 3D entities which were both rather cumbersome to create and required interpreting in order to be constructed. Inefficiencies in design interpretation in both ways from-design-to-technical drawing and from-technical drawing-to-construction led to a reluctance to design and build free forms that were hard to translate to and from 2D representations. Therefore, BIM acquires designs in the form of objects defined as parameters. All information is interconnected and greatly error-proof. Information can be retreived from BIM for cost estimation, sourcing analysis etc. and in many cases for creating feedback for design process while in progress. Building Information Modeling has, in a way, replaced the traditional architectural communication to contractors through drawings and other means of interpretation.

2.4 Mass Customization

Architectural design has always been a model of an information system. Drawings had been elaborate representations of constructive information. However, they became much more sophisticated and reliable through computerization. The more crucial effect of computerization was present in construction phase. Manufacturing industry used to require standardization, prefabrication and on-site assembly as a way to achieve low-cost production. Therefore, low-cost manufacturing also meant geometrically simple designs. While architectural design became represented as a 3D object being part of an information system and digitally-controlled machines attained the ability to produce complex shapes at fairly low costs, design and manufacturing/constructing concerns began to shift.

Production facilities producing standardized parts are now capable of mass-customizing building components. Mass-customization is a general definition for mass production of uniquely customized goods and services. Thus, in building construction, individual parts can be mass-customized to adapt various functional, formal, structural, climatic and etc. conditions.

Frank O. Gehry & Associates (Gehry Partners, LLP since 2002) is another architecture firm to be mentioned with computerization in the practice. Gehry's designs having unusual forms caused uncertainty and unease in contractor's part. The situation usually caused Gehry to end up with compromised designs. Gehry's design was shaped by physical modelling using a trial and error process. He would finalize his model as a result of an iterative progression. The model would then be computerized. In 1990, his office started searching for a computer software that could interpret complex 3D models. Initially, they used Alias software for the visualization of a large fish sculpture contract. The software was sufficient for visualization, but the representation was in terms of polygons. Therefore, they needed a software with numerical control which would provide steel manufacturers with precise information of all existing entities of the sculpture's design. Eventually, the firm adopted a software system from the aerospace industry. The software was called CATIA (Computer Aided Three-Dimensional Interactive Application). Through computerization, the model became a virtual structure thus an information system comprising each dot and link in a designed and modelled system (Url-4, 2008).

The computer model of the sculpture was then tested by constructing a paper model using a CNC machine. As a result, final construction comprised thousands of connections that were fabricated rapidly and accurately, in 1992. This was a new process for architectural construction although it was a common method in the aerospace industry. Since then, computerization has been embedded in Gehry's other projects. Most remarkably famous one was the Guggenheim Museum in Bilbao, Spain, 1997 Figure 2.2.

Figure 2.2 : The Guggenheim Museum, Bilbao, Spain, 1997

The museum was initially concieved as a sculptural form and then translated into digital information rather than having digitally born. In the fabrication process, structural parts and nodes were marked and coded. On site, all pieces were assembled according to the information retrieved from the computer model.

Another notable example of mass-customization in architecture is the Cockpit Building in an Acoustic Barrier (Figure 2.3) by ONL (Kas Oosterhuis_Ilona Lénárd) team. The team created the architectural design with the approach they define as non-standard architecture. Each part being unique and having different dimensions, this design seemed to have many setbacks at first glance. However, ONL aimed at proving that non-standard architecture could be achieved using standard materials and processes (Url-5,2008).

In doing that, they followed a path they called *File-to-Factory*, a method where they transferred architectural design data directly to production. This method allowed them to design NSA (non-standart architecture) with parametric detailing, a method that handles different functions with the same nature but with changing parameters. The scripting of design and conversion of scripts into autolisps of manufacturers demonstrated their notion of *File-to-Factory* method in construction (Boer, 2005).

Figure 2.3 : Hessing Cockpit in Acoustic Barrier, Utrecht, 2005

As mass-customization finds its practice in wider area, we find several variations of unique approaches. Another form of mass-customization was used in the WaterCube; the nickname of National Aquatic Centre in Bejing, China. The design contract was won by Arup and architectural firm PTW of Sydney, Australia, with CSCEC from Beijing and Shenzhen, China.

The building is a simple cube. It comprises steel space frames, and ETFE (Ethylene tetrafluoroethylene) cladding pillows. The Water Cube’s space framing is a complex 3D structure inspired from soap bubble foam and based on Weaire-Phelan structure (Carfrae, 2007).

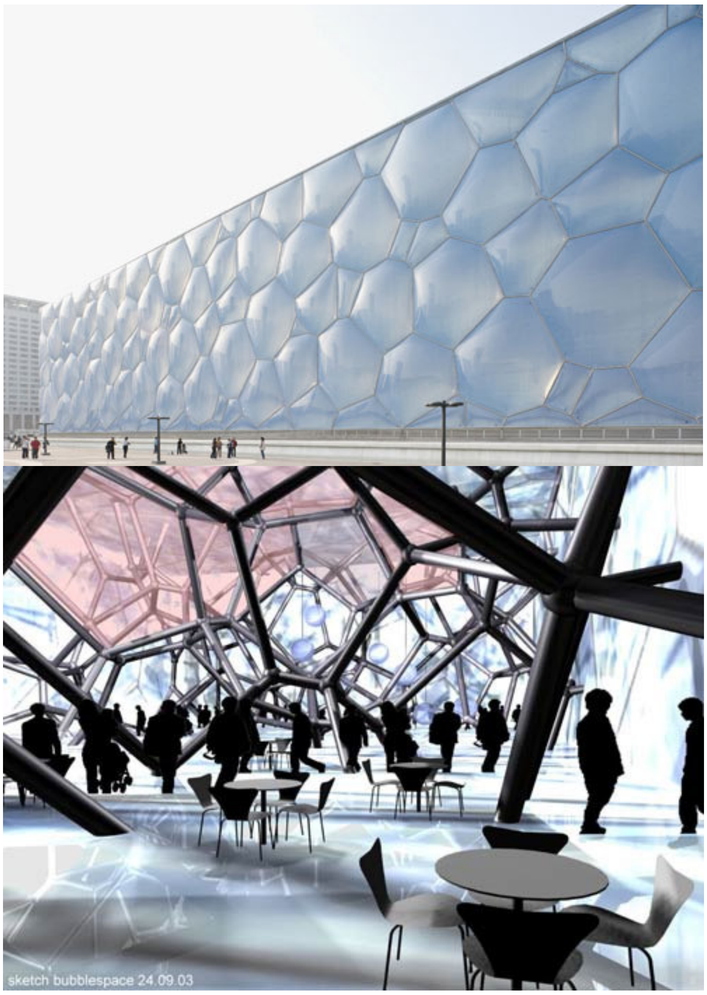

Figure 2.4 : The WaterCube- Swimming pool complex built for Olimpic Games 2008, Bejing

Arup modeled the building using Bentley/Structural and MicroStation TriForma software. The structure was exported to a structural analysis program for engineering upon being modeled in 3D wire-frame. A text file was created from the analyzed model. Then, a 3D model of the steel structure was generated by writing a VBA (Visual Basic for Applications) routine in MicroStation. VBA scripting provided team members with the ability to transfer information very efficiently from one platform to another. They could also use the 3D structural model by converting to STL file for rapid prototyping (Arup, 2006). The Water Cube's exterior cladding is made of 4,000 ETFE bubbles, with seven different sizes for the roof and 15 for the walls, largest bubbles being 9.14 m. across. EFTE is a kind of plastic named as fluorocarbon-based polymer. ETFE pillows are only 0.2 mm in total thickness and have high corrosion resistance and strength, and high melting temperature with no emission of toxic fumes due to ignition.

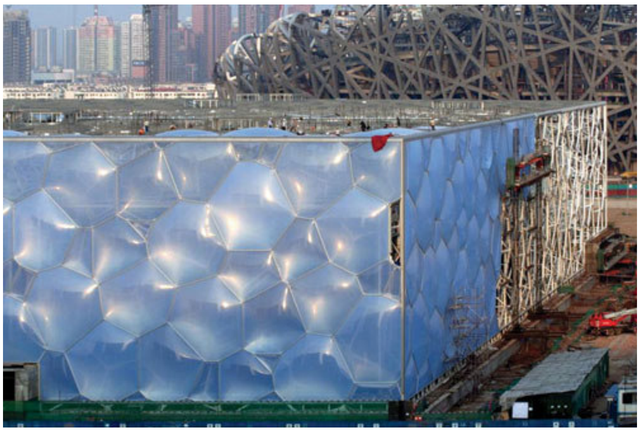

Figure 2.5 : The Water Cube during construction

Moreover, it is also capable of bearing 400 times its own weight. With its non-stick surface, EFTE is self-cleaning and recyclable. When compared to glass, ETFE film is 1% the weight, transmits more light and has 24% to 70% lower installation cost. Although it is prone to punctures by sharp edges, it is mostly used for roofs. The film is also very flexible in sheet form thus it can stretch to three times its length keeping its elasticity (Url-6, 2008).

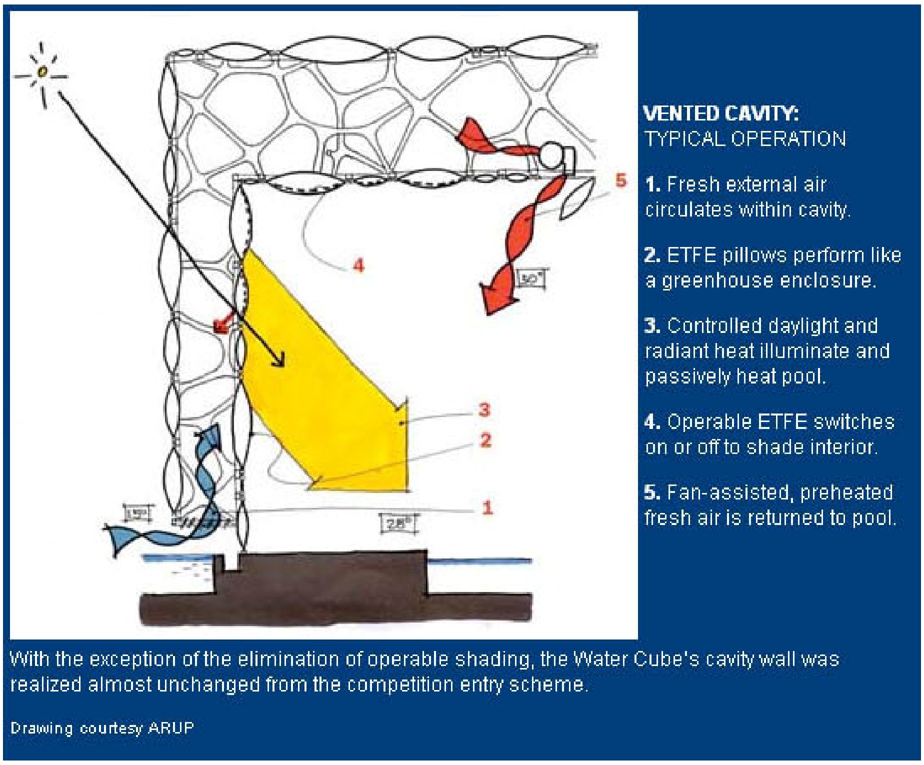

Figure 2.6 : Illustration of Vented Cavity Operation in WaterCube

The Water Cube is now fully operational. Some of the operations like ventilation running in the building are autonomous. Therefore, these operations make the cube appear like a robotic structure in terms of autonomy.

3. TECHNOLOGIES for COLLABORATION

Technological developments today, create sound impacts on life as a whole. Major disciplines that are assumed to be or have already started affecting architecture have new paradigmal promises they hold for the profession. Architectural practice can be transformed within this transdisciplinary context, once collaborative contribution can be integrated. Architectural entity may become the end-product of a unique process created within a transdisciplinary nature and may eventually have the qualities of *growth.* In the future, collaboration with the technologies in concern may provide a way of avoiding the need for brute force for existence of architectural entity.

3.1 Robotics

Robotics is the science and engineering of robots. The term as a whole embodies the design, manufacture, and application of robots. This field overlaps with electronics, computer science, artificial intelligence, mechatronics, nanotechnology, and bioengineering.

A robot is either a mechanical or a virtual artificial agent. Although robot as a word refers to both hardware and software agents, the virtual ones are usually referred to as bots. Robots are mainly electromechanical systems that give the sense of autonomy with the intent of their own.

Robotics is a huge area of the science and engineering of robots. However, not all types of robots are within the scope of this thesis. Robots in this domain are two types one of which is physical industrial robots used in manufacturing and constructions. The other type in concern is autonomous robots having embedded intelligence.

Another definition of a robot is:

> "*An automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications" (Url-7, 2008).*

Robots are present in various areas of the construction sector. They are integrated in the manufacturing of parts, in on-site operations and in buildings once they are fully operational. The use of robots is also not always very easy to integrate. Robots are experts but in limited array of tasks that they are made to perform. However, like many other advances in technology, robotics in construction is becoming more and more sophisticated. There are many construction firms working on development of robotic operational opportunities for construction sites (Sebestyen and Pollington, 2003).

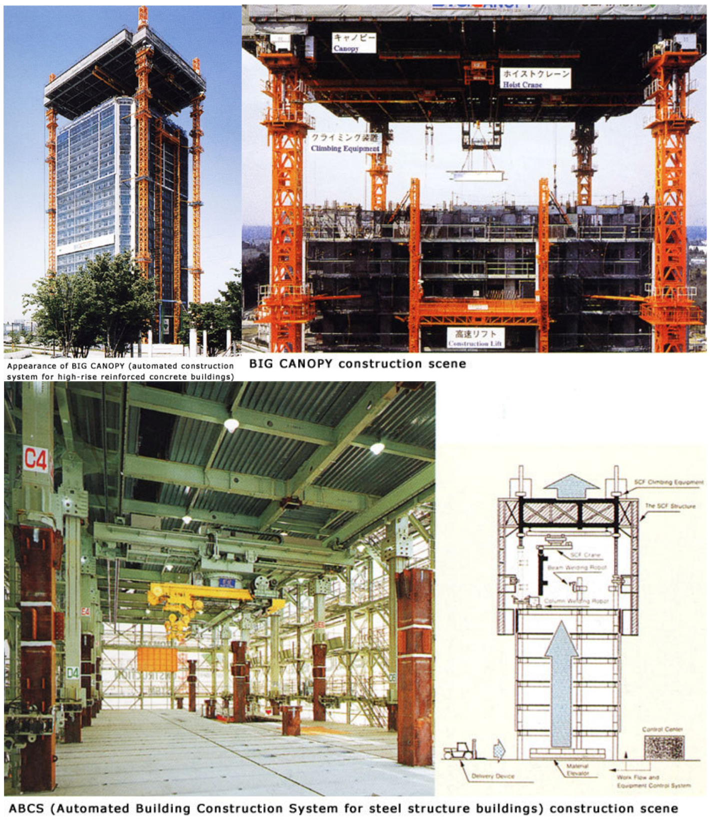

Figure 3.1 : The Big Canopy- An automated building construction system (Url-8)

Big Canopy, is an automated building construction system created by the Obayashi Construction Firm (Figure 3.1). Big-Canopy starts with four temporary towers erected on four corners of a building site for bearing the canopy. Prefabricated segments and other construction materials are carried to their spots by the cranes attached to the canopy on tracks. The tracks let cranes move on easily, thereby allowing many jobs to be done simultaneously. The canopy moves up in two storey increments. Upon completing two floors, the canopy climbs up. This goes on until when the top floor is finished. In the end, the canopy is taken down and removed. Labor savings is reported as 60 % (Url-8)

There are several other firms working on improving automated construction systems for their on-site assembly procedures. These systems are cutting labor costs and providing means of perfection to construction. They can be digitally controlled and run on many on-site operations. Robotics for construction sites is mainly focused on assemblying operations. Other industrial robots linked with constructions are manufacturing robots to produce the parts that are assembled on-site.

The other type of robots is the autonomous robots. Autonomous robots have Artificial Intelligence embedded in them and they do not only serve for building construction purposes but also are part of the building it constructs. They are fictive for the time being, however they will be real in the future.

3.2 Artificial Intelligence

Robotics and Artificial Intelligence (AI) need to be analyzed with a complementary approach as they work together when most automation systems are the case.

Artificial Intelligence is the science of simulating intelligence. It is a system that interacts with and adapts to its environment. The term is attributed to John McCarthy who is a mathematician and the developer of the programming language LISP (list processing). However, the concept of creating synthetic intelligence is currently known to date back to 3000BC when bead-and-wire abacuses, considered as the first computers were created (Url-9).

Marvin Minsky who co-founded the MIT AI Laboratory with John McCarthy introduced a set of six levels that an intelligent machine would pocess:

- *Innate reactions- innateness in interactions with the environment. Calculators would exemplify innateness as it is an expert in responding when numbers or operations are entered*
- *Learned reactions- acquired reactions as reflexes towards the environment. The knowledge is learned through interaction.*
- *Deliberative thinking- reasoning, planning, selecting the best next move based on information in hand.*
- *Reflective thinking- organizing the results of deliberative thought, and links them to their patterns to reflect towards future actions.*
- *Self-reflective thinking- adding a concept of self. It brings knowledge about limitations and constraints to what can be achieved and what is impossible.*
- *Self-conscious thinking- incorporating the perceived opinions of others and evaluates them for self-improvement (Minsky,2005).*

Generation of learning and flexible systems instead of heavy programming systems is an important problem of AI in terms of creating autonomous building systems. Autonomy is part of how robotic buildings will be executed from digital information. Many robotic structures may fake autonomous systems however, what is really intended here to reach is an autonomous building architecture resembling life in many aspects. There are some examples of robotic buildings in the next section. However, most of these structures do not possess AI, at all.

3.3 Robotic buildings composed of programmable parts

Since the notion of smart houses has been introduced to building construction, there has been many developments in automated systems embedded in buildings. Buildings are much smarter now. However, robotic buildings in concern have the potential of being autonomous structures as well. Once these buildings are built as programmable parts right from the beginning, they may well be directed from a central commander like our brains that is in control of our limbs, organs, cells, DNA etc. This thesis is somewhat a showcase of how close current technologies are to an architectural world in which buildings are organic, autonomous and self-sustaining entities. Although that level has't been reached yet, there are implications of a future quality of buildings as being robotic.

Some robotic structures are employed in limited parts of buildings like facades only. FLARE is such a facade system (Figure 3.2). The system has pneumatic tiltable metal small 3D parts. When these individual parts are tilted, they reflect various tones of light depending on their direction, thereby resembling moving pixels of images.

Figure 3.2 : Changing effect on facade when system is in operation (Url-10).

Although they may seem like display units, they can demonstrate quite impressive scenes. Therefore they are quite inspirational in terms of creating strong sparkles for functional alternative solutions. Flare system is created by Interactive art and design company Whitevoid for the ”Next Art & Technology exhibition” in Arhus, Denmark. The system is defined as kinetic ambient reflection membrane.

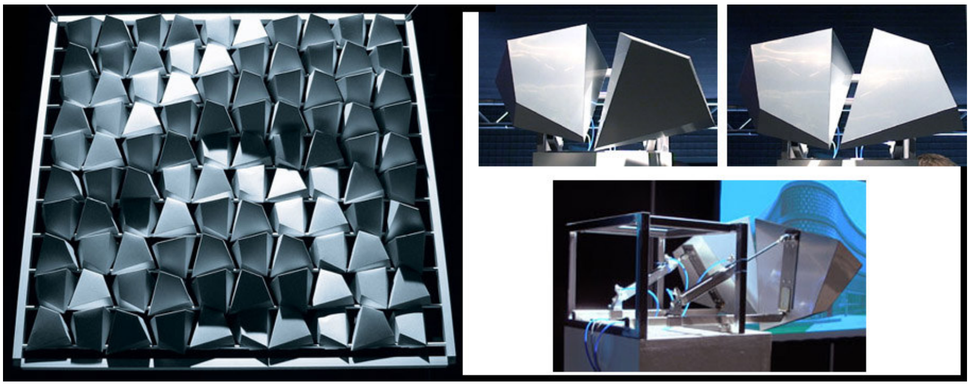

Figure 3.3 : Pneumatic mechanism of FLARE building facade system (Url-10).

The tiltable metal parts are controlled by pneumatic cylinders (Figure 3.3). Therefore, the cylinders are computer-controlled to create various designs of surface animation. As each part is individually controlled, the system is quite generative and gives the impression of a living organism (Url-10,2008).

Figure 3.4 : Falkirk Wheel in Scotland opened in 2002 (Url-12)

Not all kinetic structures are limited to skin of the buildings. Some are dynamic at the core of their structure and some are only kinetic but not robotic in essence (Figure 3.4).

The Falkirk Wheel is a rotating lift to transfer boats between two canals at different altitudes. The two canals are the Forth and Clyde Canal, and the Union Canal in

Scotland. A height of 24 metres had to be traversed between two canals (Url-11,2007).

The wheel draws a circle of 35 metres in diameter. Two arms of the wheel carry 25 meter long caissons that are filled with water. The caissons always weigh the same according to Archimedes' principle, floating objects displace their own weight in water, so when a boat enters a caisson, the same amount of water weighing the same as the boat leaves the caisson. However, this is not what keeps the structure in motion. It is the electric motors powering the facility to keep rotating. Therefore, this structure may be classified as kinetic rather than robotic. Rotation is the way that the structure performs its function. There are similar structures used in residential buildings.

An early example of rotating houses is Villa Girasole built in Verona, Italy between 1929-35. The reason it was rotating was that the builder of the house who was an engineer, wanted the house to track the sun like the sunflowers (Url-12, 2008). Another solar tracking structure called the Gemini House was designed by Roland Mösl, 1992. This time a rotating solar panel resembling an extruded arc would route around a cylinderical building. The structure generated its own energy for the tracking function.

One example of the most recent rotating structures in architecture is the Rotating Tower of Dubai in construction. The tower is designed by Italian architect Dr. David Fisher.

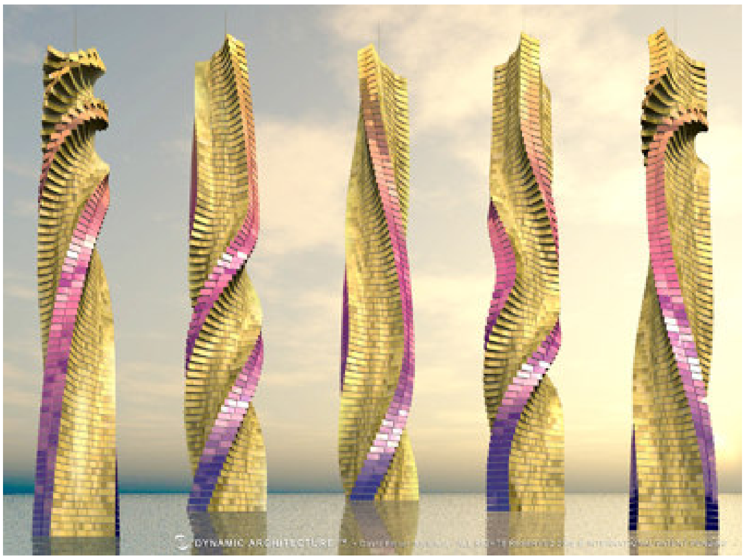

Figure 3.5 : The Dynamic Tower of Dubai, by Dr. David Fisher, due 2010 (Fisher, 2008)

It is announced that the building will have 80 floors and be 420 meters tall. Apartments will be 124 and Villas will be 1,200 square meters. The structure will be able to generate its own electricity with 79 wind turbines placed between its 80 rotating floors (Fisher, 2008). Therefore, the structure does have the potential of being classified a robotic as it is designed to appear autonomous with intent, will interact with its environment, will have embedded intelligence, will be able to make axial movements and rotations and will be an expert in sheltering its inhabitants as one or more tasks expected from it.

Figure 3.6 : Great Dubai Wheel Hotel with sight capsules, project by Royal Haskoning Architects (Url-13).

Rotating structures have also been built for entertainment purposes. The Great Dubai Wheel (Figure 3.6) is a concept created as a hotel and sight capsules (Url-13, 2008). However, none of these buildings are built with a manner in which they are considered as autonomous structures.

Obviously, a robotic structure would have a system of sensors, actuators, assemblies and controllers etc. It would need to be adaptive in the sense that it would be programmed to interact and learn. Also, it would be adaptive not only in the skin but also with all building elements. Additionally, it would carry the potential for surprise.

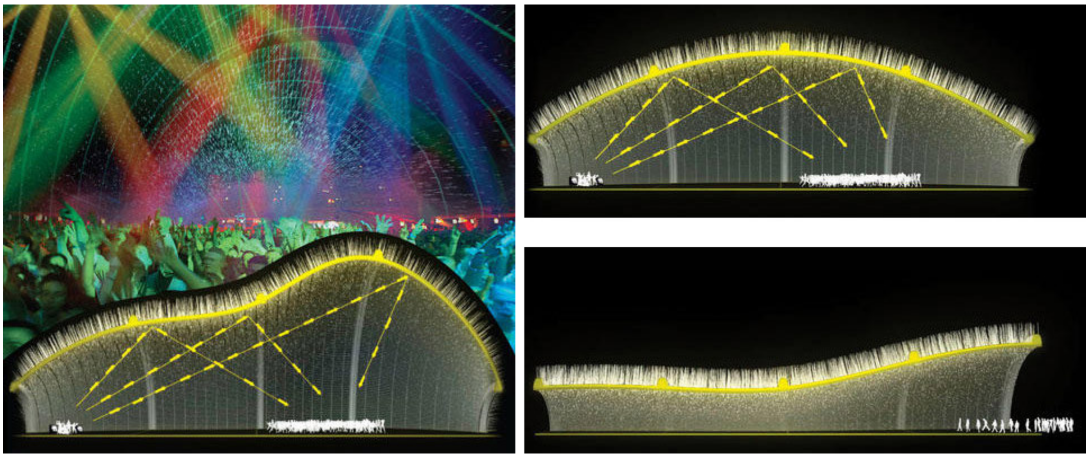

Figure 3.7 : Rendering of the Rave Space by Jason K. Johnson (Url-14)

A close example for such a structure is the Rave Space project (Figure 3.7) created in the University of Virginia School of Architecture's interdisciplinary seminar called the Robotic Ecologies. It is a night club that is adaptive to crowdedness inside or outside. The Rave Space structure resembles a living organism with its ability to interact with the environment and to change shape in order to conform to changing conditions. The structure's dimensions change according to circulation of crowds and acoustic necessities (Url-14, 2007).

3.3.1 A Network: Decentralized Programming

An autonomous system is expected to be capable of taking actions of its own to some extent. The notion of autonomy in that sense brings about a modular system compiled of self-aware parts still carrying the information of the whole larger system that they belong to. This notion is quite similar to cells in organic bodies having the consciousness of the whole body while carrying out their own tasks coded in their unique existence.

Trigon system is designed as a self-assembling, self-replicating, self-manufacturing, and self-sustaining building system by A. Scott Howe PhD, from Plug-in Creations Architecture, and Hong Kong University Dept. of Architecture and Dept. Mechanical Engineering, in 2005. The system was envisioned as an autonomous or teleoperated robot to land on a planetary surface. It is expected to build copies of itself for further distribution before human crews arrive.

Figure 3.8 : Lunar habitat scenario for Trigon modular system built up with self-assemblying parts (Howe,2006)

This is a panel-based robotic system designed for the assembly of reconfigurable structures using a parametric model (Howe, 2006).

Figure 3.9 : Functional mock-up showing self-assembling structures (Howe,2006)

Trigon system is quite succesful in terms of freeing the system from being dependant on on-site assembly procedures. Decentralized programming with parts that are embedded with intelligence is a brilliant way to attain autonomous systems (Figures 3.8 - 3.9). However, the system is still too cumbersome when miniturizing technologies are considered. When this system can be achieved at the atomic level, the output will be as efficient as a living body.

3.3.2 How to build it

A robotic system requires very sophisticated production techniques in order to accomplish its deeds. Nevertheless, a very sophisticated production can be achieved by again using robotic manufacturing methods in production.

Three dimensional (3D) printing is a method of rapid prototyping (RP) and rapid manufacturing (RM) with skipping the molding phase of many conventional production techniques. 3D printing is usually achieved by building up successive layers of certain materials suitable for the technique. Among commonly used applications are design visualization, prototyping/CAD, metal printing, architecture, artistic expressions, education, healthcare, entertainment/retail, etc. However, 3D printing technology is also being developed by biotechnology firms and universities in tissue engineering applications where organs and body parts are built using inkjet techniques. Names of these techniques seem to have popped out from science fiction media: computer-aided tissue engineering, organ printing, or bio-printing using bio-ink in an ink-jet printer. These techniques also use a similar method of laying successive layers of living cells onto a gel medium and of incubating the building up of three dimensional organic structures.

In the case where things can be manufactured from scratch within very few processes, a new way of design thinking flourishes. While design input has been transformed into information, literally to bits, manufacturing and construction technologies tend to transform bits into atoms as mentioned earlier.

Figure 3.10 : A hand-held piece created by direct-metal printing technique designed by Bathsheba Grossman, (Url-15)

The printing technique used in production of the piece in Figure 3.10 produces a composite steel-bronze metal. The piece comprises four printed metal parts and nine tungsten carbide bearings to add static structure to it (Url-15).

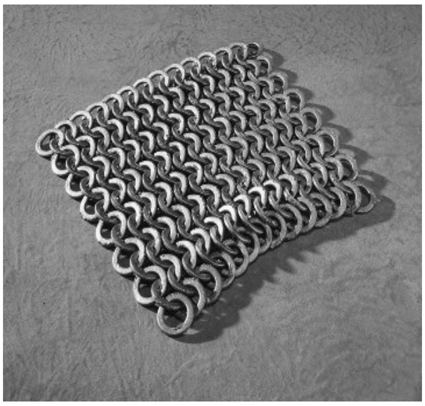

Figure 3.11 : A fabric pattern designed by FOC, made by SLS
(Hopkinson, et al, 2006)

Selective laser sintering (SLS) is an additive RP technique. SLS produces 3D shapes out of metal, plastic or glass etc. by fusing powder. The technique uses digital data for scanning cross section and fusing powder at designated coordinates. The tray that is holding the raw material is lowered layer by layer. When compared with other RP techniques like Stereolithography (SLA) and Fused deposition modeling (FDM) SLS has an advantage of producing parts without needing support.

Stereolithography (SLA) is also an additive technique which uses ultraviolet (UV) laser. This technique, however, is liquid-based rather than powder-based as in SLS. Digital data determines the coordinates on the surface of resin should be solidified. This time a vat of resin is lowered layer by layer until the part is created (Hopkinson, et al, 2006).

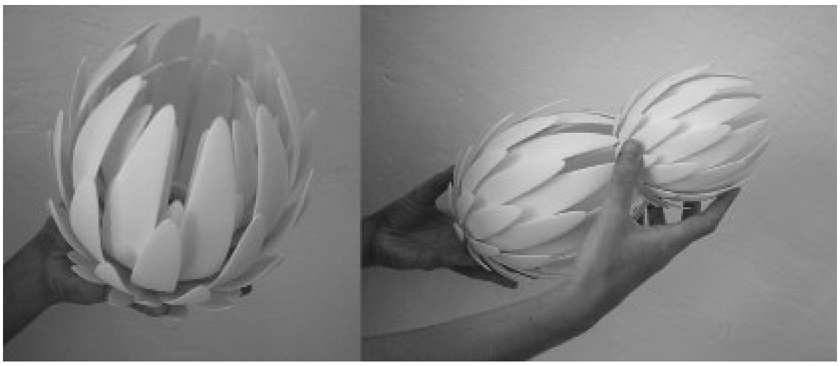

Figure 3.12 : Nested “Lily” and “Lotus” lampshades made by SLS, designed by FOC, made by SLS (Hopkinson, et al, 2006)

There are several design offices integrating mathematical thinking in creating new designs for digital fabrication. These designs introduce new ways of thinking refined to suit rapid manufacturing techniques Figures 3.11-3.12.

Figure 3.13 : A sculpture by Carlo H. Séquin, a professor of Computer Science division at UC.Berkeley, made by FDM (Url-16)

FDM, is a type of RP/RM technology that was developed in the late 1980s and was commercialized in 1990. Like most other RP processes FDM works on an additive principle by laying down material in layers. A plastic filament or metal wire is deposited from a coil and supplies material to an extrusion nozzle which is equipped with thermal processing ability to melt the material. In a similar manner to stereolithography, the model is built up from layers as the material hardens immediately after extrusion from the nozzle. The structure in Figure 3.13 is manufactured by using FDM (Url-16).

Instant Production

Among the rapid prototyping experiments there is a unique one which can be summarized as the materialization of real furnitures from freehand gestures made in the air (Figure 3.14). Members of the Swedish design group FRONT have experimented with a method where two advanced techniques are combined.

This whole new experiment was done in 2006 and started off from a question (Url-17, 2006):

> *"Is it possible to let a first sketch become an object, to design directly onto space?"*

Figure 3.14 : Hand sketches made in the air by FRONT (Url-17)

Initially, deliberate hand gestures are made for design. The gestures are percieved as pen strokes and are recorded with Motion Capture technique and become 3D digital files Figure 3.15.

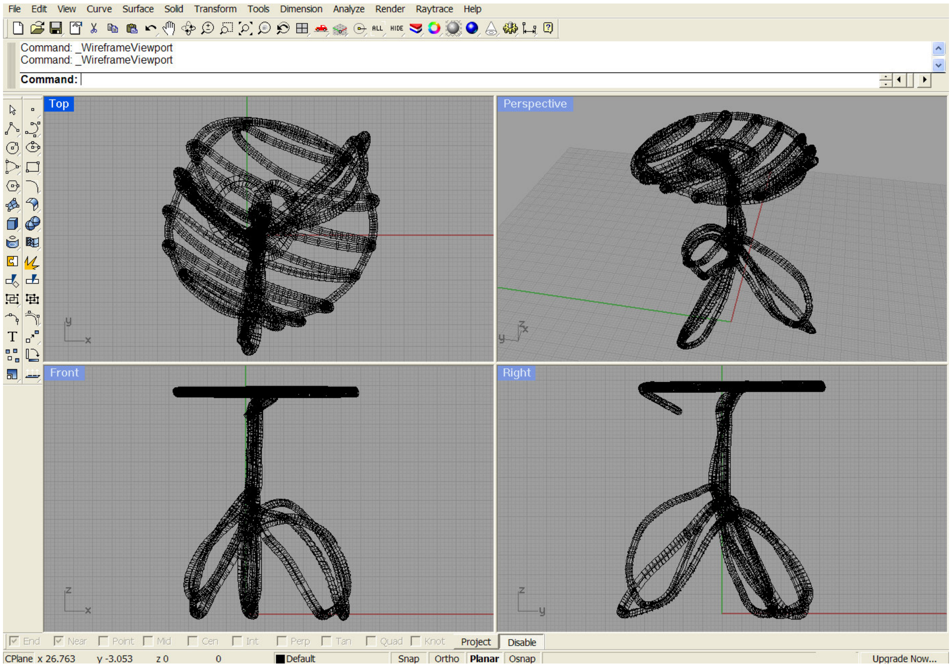

Figure 3.15 : Hand sketches made in the air by FRONT (Url-17)

The 3D files are then transmitted to Rapid Prototyping. At this final stage, they get the hard copy of their hand sketches they just made in the air (Url-17).

Micro and nanomanufacturing are expected to be affected by the improvements in RM. Through microelectronics photolithography and microelectromechanical systems (MEMS) , new freeform processes may emerge. Development of biocompatible materials will enhance successful integration of RM applications in biomedicine. Mass customization will improve in accordance with consumer needs. Future RM will be even better, faster and cheaper (Hopkinson, et al, 2006).

Shapeways is a new brand for making RM accessible for individuals. They are accessed through their website where they provide an online design creator. Shapeways also have these pages where new designs of users are displayed. The website may become a place for social networking where designs are shared and discussed by even non-professional designers. Rapid 3D objects can be manufactured without the need for high proficiency in 3D modelling tools (Url-18, 2008).

When building construction is the case, automation systems need some adaptation. First of all, architecture deals with elements that are among the largest *things* on earth. So the products of building architecture should be handled in a carefully elaborated manner. When 3D printing is the case, engineers come up with several possibilities differentiating from other robotic construction techniques. The idea of 3D printing in construction requires intricate solutions to come up with.

“Contour Crafting” is among these solutions. It is a construction process adapted from 3D printing principles. The system is a scaled up version of rapid prototyping/rapid manufacturing machines for printing 3D objects designed or digitized by using CAD/CAM software. Contour Crafting technologies started off to adapt the 3D printing technology for rapid home construction as a way to rebuild after natural disasters Figure 3.16.

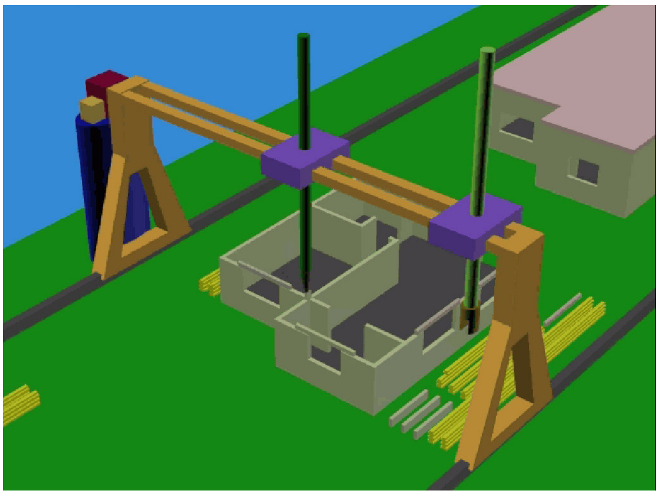

Figure 3.16 : Contour Crafting construction system (Photo courtesy of Dr. Khoshnevis) (Url-19)

CRAFT stands for Center for Rapid Automated Fabrication Technologies. The construction process of Contour Crafting is being developed by Behrokh Khoshnevis at the University of Southern California's Information Sciences Institute (in the Viterbi School of Engineering). The process utilizes a computer-controlled crane to build structures rapidly with no manual labor Figure 3.16 - 3.18 (Url-19).

Figure 3.17 : Corrugated wall production by CC system (Photo courtesy of Dr. Khoshnevis) (Url-19)

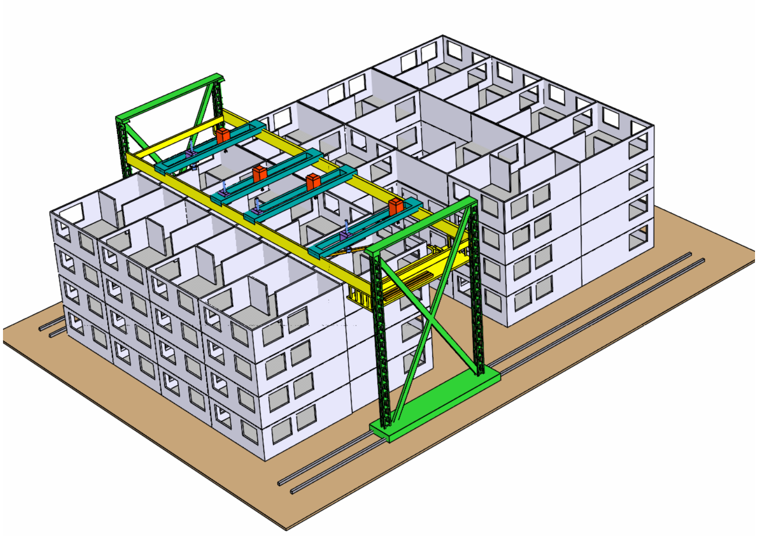

Figure 3.18 : CC system for higher rise structures (Photo courtesy of Dr. Khoshnevis) (Url-19)

Dr Khoshnevis gave the information that a full scale machine and 6 ft wall sections (Figure 3.17-3.19) have been built and that they plan to build small demonstration houses next year. A large manufacturer of construction equipments, Caterpillar, has decided to support research on the Contour Crafting automated construction system. The main goal of Dr.Khosnevis is to be able to build full-scale houses in hours (Url-20, 2008).

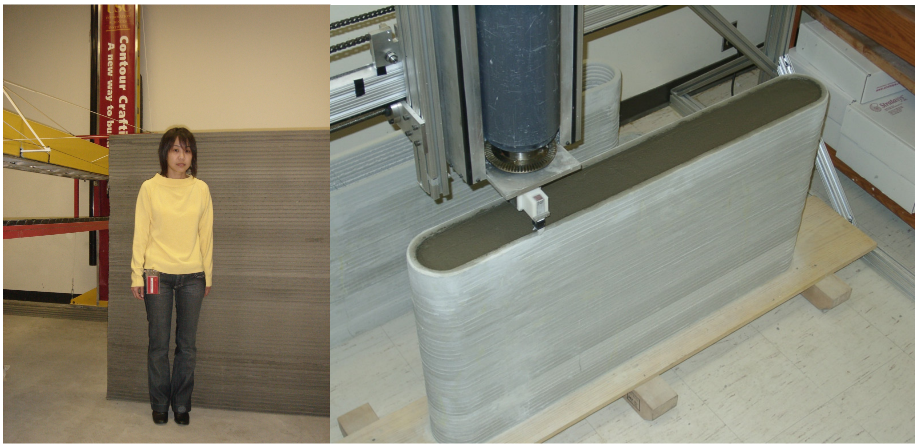

Figure 3.19 : Full scale wall production (Photo courtesy of Dr. Khoshnevis) (Url-19)

Another masonry system for digital fabrication is the work of Tobias Bonwetsch, Fabio Gramazio, Matthias Kohler of ETH (Swiss Federal Institute of Technology) Zurich. This system is designed as an additive process as in the work of Khosnevis. In their work, the designers of the process had investigated and modeled a more sophisticated and generative approach to mobile bricklaying robots (Figure 3.20) for construction on site (Url-21, 2008).

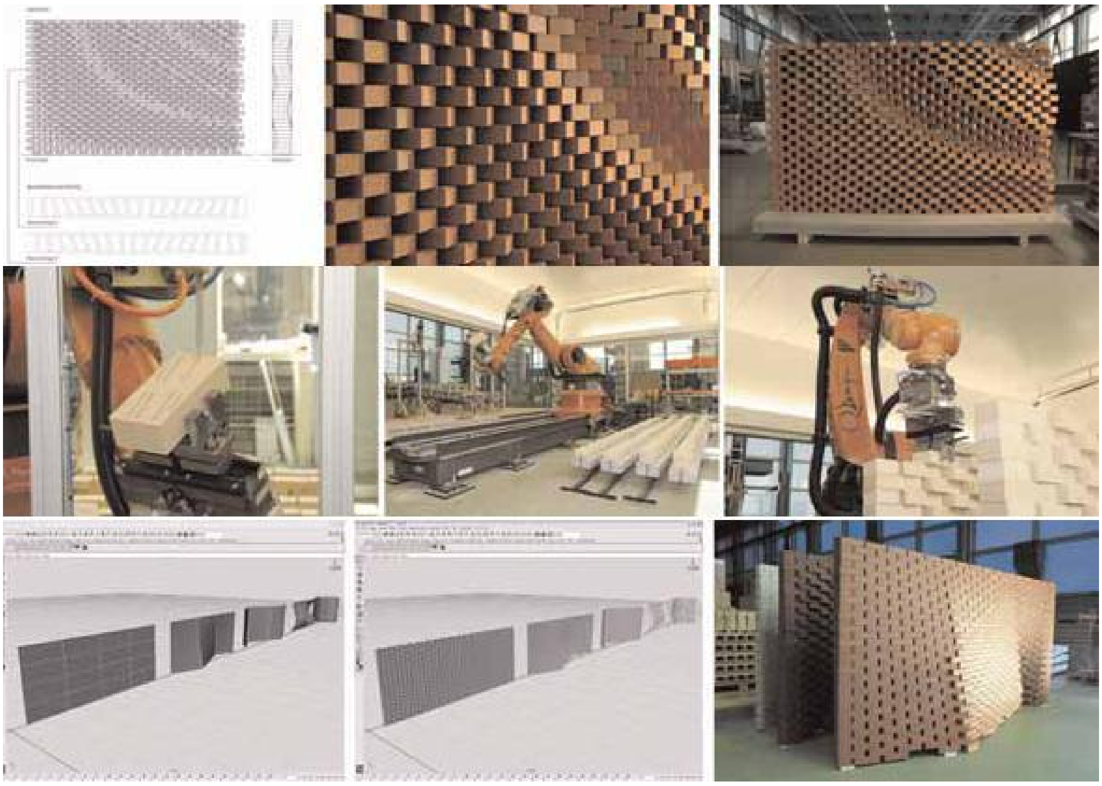

Figure 3.20 : Prototypical application of digitally designing and fabricating non-standardised brick walls (Url-21)

All of these concepts are diverse developments in construction and manufacturing systems and will continue their improvement. However, they are either device and/or support dependent during construction. Therefore, biosystems are not due to the capacity and dimension of their manufacturing or assemblying devices. They are only code dependent. And they are tiny.

3.4 The tinier the more sophisticated

Nanotechnology deals with dimensions from approximately 1 to 100 nanometers. It is the understanding and control of matter at a scale where unique properties enable new applications. By looking at dimensional comparisons, one can get a glimpse of nanoscale. A sheet of paper is about 100,000 nanometers thick, a single gold atom is about a third of a nanometer in diameter.

The term *Nano* comes from the Greek word "νᾶνος", meaning *dwarf*. Nano, as a prefix, implies one billionth of a unit. Nanotechnology involves imaging, measuring, modelling, and manipulating matter at a nano-scale. A nanometer is one-billionth of a meter (Url-22, 2004).

Nanotechnology is an interdicsiplinary field involving skills from Chemistry, Biology, Physics, material science, electronics etc. Although nanotechnology has been treated as a hype over some whimsical ideas, neither the term nor the theme is new. However, its fame created a vortex in nanoscience and attracted much attention from necessary fields to make the technology viable. Workers of nanotechnology do not all have far sighted agenda. Some only work on refining manufacturing thechnologies, or improving material capabilities or adding high quality to cosmetic, automative, medical or other products and operations at nanoscale i.e. less than 100 nanometers. Nevertheless, another group of members in this field are foreseeing a revolution having an impact as that of the Industrial Revolution on life as a whole (Drexler, 1991). Such a concept of future forecasting is heavily criticised and rejected by positioning nanotechnology and nanoscience as science fiction rather than science. However, it is only a matter of time before science fiction becomes science (Cernan, 2001).

Table 3.1 : Examples for Understanding Nanoscale

Scaling Examples	Dimension
Head of a pin needle	1,000,000 nanometers
Hair	100,000 nanometers
Red blood cell	10,000 nanometers
Circuits on chips	1,000 nanometers
Virus	100 nanometers
Buckyball* *(60 Carbon atoms forming a sphere)*	1 nanometers
Hydrogen atom	0.1 nanometers
* Buckyball will be explained later in main text	

Nanotechnology had two major developments in the early 1980s with; the birth of cluster science and the invention of the scanning tunneling microscope (STM). Fullerenes were discovered in 1986 and carbon nanotubes a few years later. Buckyball is a new form of elemental carbon made up of 60 Carbon atoms forming A sphere named after architect-engineer R. Buckminster Fuller who had designed geodesic domes. They appear to have a structure of interlocking hexagons and pentagons. They look almost like a soccer ball.

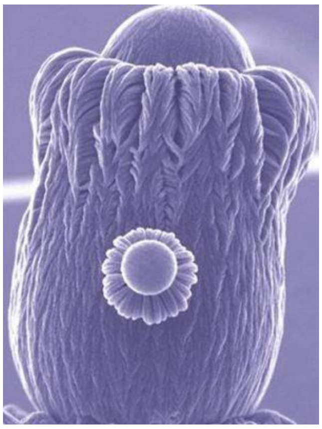

Figure 3.21 : 3D Si composite nanostructures, taken with a scanning electron microscope, by Ghim Wei Ho (Url-23)

Table 3.2 : Chronological Progress in Nanotechnology

Date	Event
1871	Scottish physicist James Clerk Maxwell talks of “demons” that could manipulate atoms one by one
1930’s	Arthur Robert von Hippel of M.I.T takes up interest in molecular design
1959	Richard Phillips Feynman talks of manipulation and control of” things” that is individual atoms and molecules at very small scales at his famous speech titled “There’s Plenty of Room at the Bottom,”
1960’s	Norio Taniguchi from Tokyo Science University talks of the term “molecular engineering”
1974	Norio Taniguchi uses the term “nanotechnology” to define the precision technology at the level of one nanometer in his article "On the Basic Concept of 'Nano-Technology'," Proc. Intl. Conf. Prod. Eng. Tokyo, Part II, Japan Society of Precision Engineering, 1974.)
1981	Scanning Tunneling Microscope is produced. A micro-nanoscope with which height of each atom could be determined.
1981	Kim Eric Drexler publishes Molecular engineering: An approach to the development of general capabilities for molecular manipulation
1985	Buckyball C60 molecules are also called buckyballs.
1986	Engines of Creation In the 1980s the basic idea of this definition was explored in much more depth by Dr. K. Eric Drexler, who promoted the technological significance of nano-scale phenomena and devices through speeches and the books Engines of Creation: The Coming Era of Nanotechnology and Nanosystems: Molecular Machinery, Manufacturing, and Computation and so the term acquired its current sense.
1990	A group of IBM physicians wrote “IBM” using 35 atoms of Xenon element
1991	Unbounding the Future: the Nanotechnology Revolution is published K. Eric Drexler, Chris Peterson, and Gayle Pergamit
1996	Richard Errett Smalley chemist from Rice Üniversity and his group Sir Harry Kroto and Robert Curl won a Nobel Prize for their synthesis of a new form of carbon, C60
2008	Nanotubes grown in the form of 3D Obama pictures

Other very popular nanoscale structures are carbon nanotubes. They are extremely thin, seamless cylinders made of carbon atoms. Diameter of a carbon nanotube is about 10,000 times smaller than a human hair (IBM Research, 2008). They are structural and extremely strong compared to their physical appearance that is not visible to human eye without necessary devices. A research team led by John Hart of Michigan University has recently created carbon nanotube images (Figure 3.22) of a political figure to raise interest in nanotechnology in the society (Url-24, 2008). This is needed for funding which is very crucial in continuing scientific research. The details of the figure can only be seen with optical and electron microscopes. Indeed, the pictures were also taken using optical and electron microscopes. The figure's structure was made of carbon nanotubes. Carbon Nanotubes (CNTs) were grown at a high-temperature. Patterns of nanoscale metal catalyst particles were arranged in a chemical reaction in the shapes of the faces etc. There are millions of vertically grown parallel nanotubes, on the substrate.

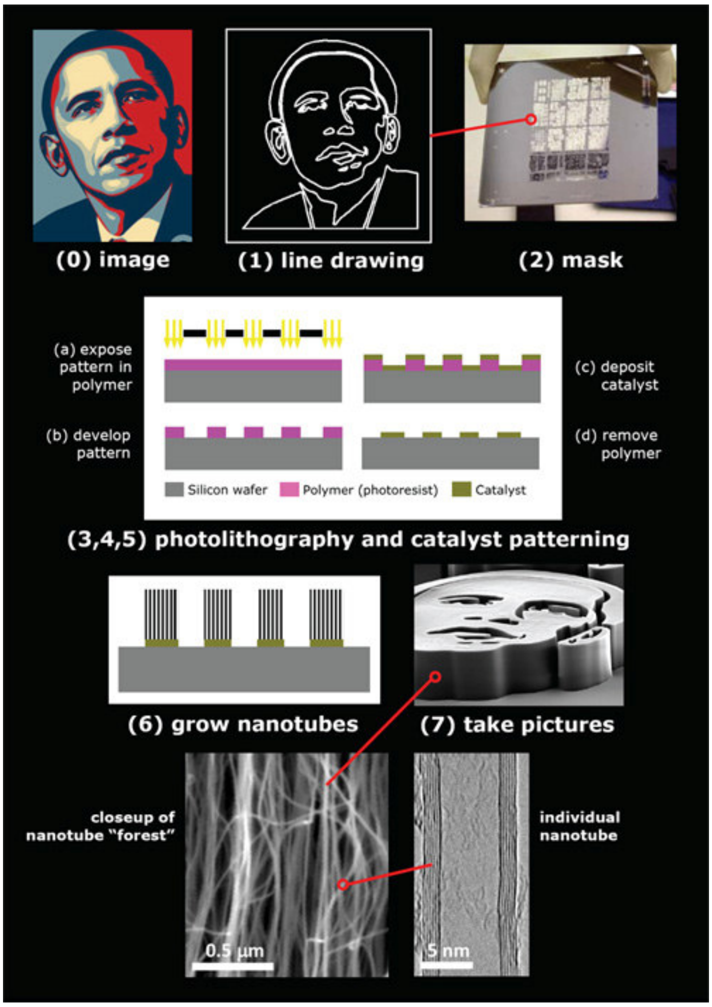

Figure 3.22 : Nanobama nanotubes growth process (Url-25)

The image was captured through microscope and converted to a line drawing. The image was then printed on a glass plate. Then ultraviolet light was projected through the masking glass plate onto a thin layer of polymer on a silicon wafer. This process patterned the polymer by photolithography. The wafer was then coated with a thin layer of catalyst nanoparticle "seeds" for nanotube growth. The remaining polymer was then removed. CNTs were grown from the catalyst patterns, by placing the wafer in a high-temperature furnace full of carbon-containing gas.

3.4.1 Nano Visions

K. Eric Drexler envisioned nanotechnology as a path on which factories would shrink to cellular sizes and be equipped with nanoscale machines. In his book *Engines of Creation* (1986) he mentioned type of machines following a program loaded to a molecular tape and able to build literally anything by manipulation of atoms in targeted manners. The machines were named “assemblers” (Drexler, 1986).

Drexler, is pioneer and popularizer of nanotechnology. He set a goal of achieving perfectly sophisticated and inexpensive control of the structure of matter. He envisioned nanomachines capable of disassembling materials such as wood or oil and then restructuring them into diamond crystals by converting the carbon atoms that are present in those structures.

Table 3.3 : Comparison table –Compiled from Unbounding the Future: the Nanotechnology Revolution (Drexler, et al, 1999)

Digital Era	Nanotech Era
Digital electronics	Nanotechnology
A Programmable Computer	A Programmable Assembler
Speed and Control at the scale of Bits ve bytes	Speed and Control at the scale of Atoms ve molecules
Information processing Revolution	Material processing Revolution
Bits at desired patterns	Atoms at desired patterns

Drexler envisioned, as well as many other pioneers working in molecular manufacturing, that the future products will be things that are impossible to build today.

In Engines of Creation, Drexler referred to Richard Feynman’s talk "There’s Plenty of Room at the Bottom", in 1959 and projected nanoscale machinery building atomically precise products.

Future productive nanosystems are being continuously developed in increments by improving instruments and techniques for working at nanoscale. There are already some very precise devices such as Scanning Tunneling Microscope (STM) for seeing and moving atoms and molecules. In the field of biotechnology, there has been many advances in DNA engineering in terms of manipulating molecular machinery. Computational modeling has also improved very rapidly. However, productive nanosystems will reach it ultimate goals by using capabilities of a much further and higher technology that will be possible through nanotechnology itself. Thus, it will recreate itself.

3.4.2 Nanotechnology in top-down approach

Nanoscale materials have far larger surface areas than similar volumes of larger scale materials. This phenomenon means that more surface is available for interactions with other materials around them eg: hydrogen storage (Yildirim and Ciraci, 2005)

The famous talk given by physicist Richard Feynman at an American Physical Society meeting at Caltech in 1959 was titled "There's Plenty of Room at the Bottom". The talk was about the problem of manipulating and controlling things on a small scale. Feynman’s initial wonder was:

> *“Why cannot we write the entire 24 volumes of the Encyclopaedia Britannica on the head of a pin?” (Feynman, 1959)*

Feynman suggested a model having precision tools to manufacture proportionally smaller sets than theirs. He fed this model with many details such as scaling issues which would bring about the notion of Van de Waals attraction which affects the way molecules stick together. He predicted that parts made at that scale would respond to gravity as null. This approach of scaling down to smaller scale is called the Top-down approach and is the currently commercialized side of nanotechnology. However, the commercialized methods are not exactly the way Feynman envisioned them to be, because his model of parts being made at smaller scales by their builders was not very feasible. Rather, the top-down approach developed by the improvements in observation and manipulation devices like the STM and Scanning Probe Microscope (SPM) (Feynman, 1959).

3.4.3 Nanotechnology in Bottom-up approach

Polymorphic material to make things may be the most desired idea for many people working with nanotechnology or even for those who are even unaware of nanotechnology. Feynman had this other question of what would happen if the technology was achieved through which atoms could be arranged one by one. Considering the unique properties that arise at the nanoscale suggested that atoms at small scale would behave due to the laws of quantum mechanics. Also, he envisioned mass production of devices as perfect copies of one another. Therefore, he pointed out that the principles of physics was not against the possibility of manouvering things atom by atom and that it could be done. He added that the reason it was not yet done was due to the scale of humans which he defined as "too big" (Feynman, 1959)

This more futuristic approach to atomic manipulation is called the bottom-up approach. Bottom-up fabrication is used to make nanostructures. These structures are exploited in terms of directing the self-organization of the intrinsic properties of atoms and molecules. The goal for this approach is to create nanostructures of high complexity.

At the nanoscale, material properties can change. They can exhibit different physical, chemical, and biological properties than they do at macroscales. The differences can be changes in color, becoming transparent, better conductivity, or changes in magnetic behavior.

3.4.4 Molecular manufacturing

The control of matter digitally at the atomic or sub-atomic scale is actually what nanotechnology is all about. Drexler has a basic way of defining it:

> *"Coal and diamonds, sand and computer chips, cancer and healthy tissue: throughout history, variations in the arrangement of atoms have distinguished the cheap from the cherished, the diseased from the healthy. Arranged one way, atoms make up soil, air, and water; arranged another, they make up ripe strawberries. Arranged one way, they make up homes and fresh air; arranged another, they make up ash and smoke." (Drexler,1986)*

Drexler's vision has also been opposed by scientists who argued that things do work differently in the context of chemistry than of mechanics. There have been debates on how molecular manufacturing will work in the bottom-up approach.

When making artificial nanoscale machines is the case, two design philosophies are concerned. One is using the macroscale engineering principles which is based on rigid materials. The smaller the fabrication gets the larger the obstacles get due to physics of nanoscale. The other philosophy is of “soft engineering” in charge when cell biology is the case. These two approaches are not similar at all (Jones, 2004).

At the atomic scale, matter is digital. Atoms don’t wear off and same kind of atoms are always identical (Hall,2005). Molecular manufacturing is a technology in pursuit of building large and perfect objects with atomic precision, rapidly and at much cheaper rates than today. Molecular machine components have already started being built, but they need to improve in certain ways.

In molecular manufacturing atomically precise parts are manufactured by molecular machines. Molecular machines work at molecular scale. The difference between cells’ proteins and molecular machines in concern is that living cells operate in liquid, at certain temperatures and are softer while MM is envisioned to work in vacuum and have a harder nature with a fast speed of operation (Hall,2005).

The outcome of molecular manufacturing will be but not limited to extremely powerful computers, perfectly manufactured goods and medical devices. To build such systems with complex atomic specification robotic mechanisms and AI of any sort will be used.

In the book “The Diamond Age” by Neil Stephensons, there is a device named Matter Compiler (M.C.). The device gets atoms from the grid of the city. Next, the M.C. outputs whatever object it is programmed to create. M.C. is a magical manufacturing machine that almost anyone would want to have (Stephenson, 2000). In nature, there is the system of self-assembly at nanoscale. Devices like the M.C. which are waiting to be the *universal printers* of tomorrow will need to start creation from scratch thus at the nanoscale, in order to mimick nature’s own manufacturing system.

4. FUTURE PROJECTION for BUILT ENTITY AS AN IMMORTAL EXISTENCE

Future is both what happens and what we create simultaneously. Marvin Minsky expresses his thoughts about visionary endeavors in his foreword for Eric Drexler's book on nanotechnology, "Engines of Creation", as follows (Drexler,2006):

> *"...how can anyone predict where science and technology will take us? Although many scientists and technologists have tried to do this, isn't it curious that the most successful attempts were those of science fiction writers like Jules Verne and H. G. Wells, Frederik Pohl, Robert Heinlein, Isaac Asimov, and Arthur C. Clarke? Granted, some of those writers knew a great deal about the science of their times. But perhaps the strongest source of their success was that they were equally concerned with the pressures and choices they imagined emerging from their societies…"*

Minsky moves on to explain that Arthur C.Clarke has also emphasized that detailed future prediction is not possible as predicting the feasible technologies that are available for that time is equally impossible. Likewise, it is equally impossible to foresee social changes that might occur. In that, he stresses the importance of building thought on sound present day technical knowledge and supporting conclusion steps in several different ways. He suggests that thoughts would gain robustness through complementary facts (Drexler,2006).

However, there is another issue on basing thoughts on sound knowledge is that the sound knowledge is becoming rapidly reorganized and reevaluated or completely altered by new knowledge at times. Nevertheless, even if visionary suggestions are based on very sound cases and mostly updated knowledge, they are subject to change.

Similarly, every week, novel scientific news are released that offer new ways of considering many facts right from the beginning. Another citation from Marvin Minsky this time, carries this notion of constant growth and change in information, when replying a student's question at an EDGE event in 2007 on his recently published book *The Emotion Machine*:

> *"...However, I won't try to identify where these might lie in the brain because research on this is advancing so quickly that any conclusion one might make today could be outdated in just a few weeks…" (Url-26, 2005)*

What should be cleared out, is that whichever a platform of sound knowledge it is that we base our visions on, it should always be considered that most sound knowledge might change or shift its consequences by time and by most recent knowledge. Still, derivative thought is actually what makes thoughts trustworthy. Apparently, merits of derivative approach can be argued more deeply, however the subject of this thesis is more of another issue , an issue of drawing lines between dots in a 3D medium. The dots in concern are representations of fields of Nanotechnology, Robotics, Artificial Intelligence and Genetics. Derivative approach is used in this work because it provides the ability to make analogies between architectural practice and other disciplines in concern. Through these analogies the author believes that she can make her final prediction on an immortal kind of building architecture.

Naturally, one should be alive in order to be immortal.

4.1 Living Spaces Will Be Organisms Rather Than Solid Boundaries

To mimick life, scientists are working on several methods. Daniel Arbuckle and Aristides A. G. Requicha from Department of Computer Science of University of Southern California are working on self-repairing, self-assembled structures and introduce a method by which structures can be self-assembled, and then repaired by identical agents that they are assembled of in case of loss or failure of members in the structures Figure 4.1. The structures are also reproductive through a process analogous to mitosis. They present a new method by which agents can assemble themselves into fully specified structures, and then repair those structures when they are damaged. As a side effect of the self-repair capacity, such structures can reproduce by a process similar to mitosis, given a sufficient supply of assembly agents.

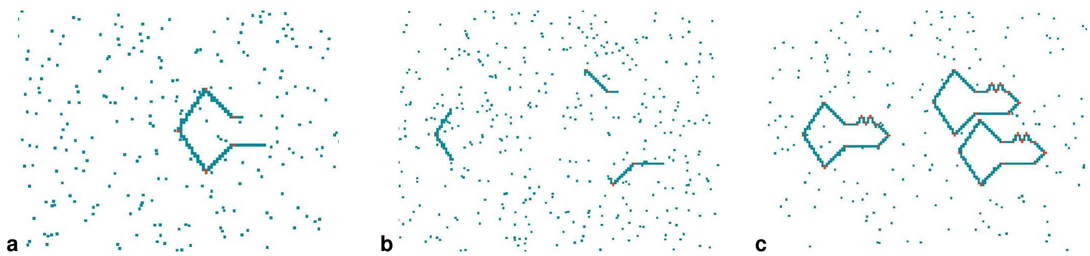

Figure 4.1 : (a) An intermediate stage of the construction of a key-like object. (b) Breaking the object into three pieces. (c) The three fully built (Arbuckle and Requicha, 2006)

The researchers based their work on initially abandoning the top-down approach in nanotechnology. Additionally, they emphasized a distributed system searching for randomness rather than precise positioning of components and therefore have robustness and self-repair capabilities as in biological systems. They offer an approach to building objects that are not scale dependent but that work best at the nanoscale. However, they emphasize the fact that their major challenge for implementing active self-assembly today comes from the hardware side referring to nanorobotics, which they believe progressing rapidly and should come to the rescue in the not-too distant future (Arbuckle and Requicha, 2006).

4.2 Genetics

The subject of “Genetics” is included in this thesis as a stepping stone for enlightening the efforts of inspirational reasoning from how nature works its way through various different forms of life. Life is engineered with Nature’s nanotechnology. The information technology that Nature is using at nanoscale is studied by Genetics. Genetics is a field of biology. It is the science of the process in which inheritance and variance factors are transmitted from one generation to the next.

Gregor Mendel of nineteenth century was among the first genetic scientists that the world has come to know. He observed inheritence and concluded that there were separate units that controlled how inheritence worked. These separate units were coined later as genes (Url-27, 2008).

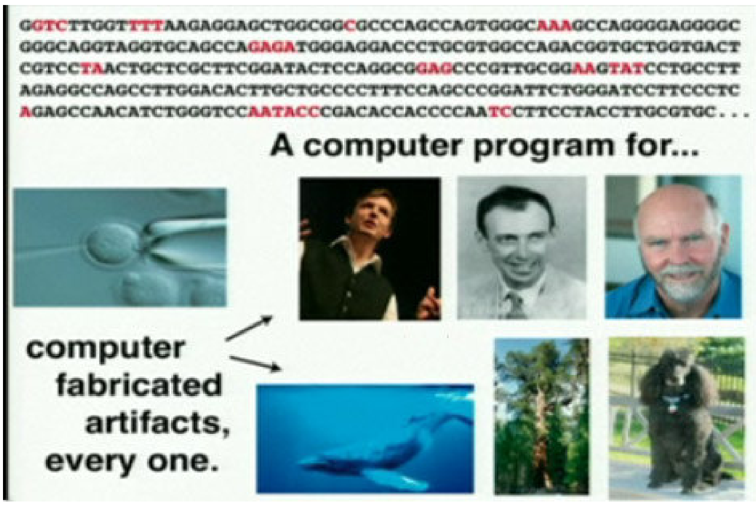

Figure 4.2 : A scene from TED Talk on DNA folding byRothemund telling that life is computation (Rothemund, 2008)

Genes are present within DNA. Therefore, DNA is discovered to be the basic molecule for genetic operations. DNAs form double helix which looks like a twisted ladder. Each strand of the helix is defined as a nucleotide chain. The nucleotides have a sequence which carries the genetic code that is inherited. This genetic code is spelled out with four chemical letters: A (adenine), T (thymine), C (cytosine) and G (guanine) that are paired as A with T and C with G (Encyclopedia Sci-Tech, 2008). Living creatures are being modelled as variations of these spells Figure 4.2 (Rothemund, 2008).

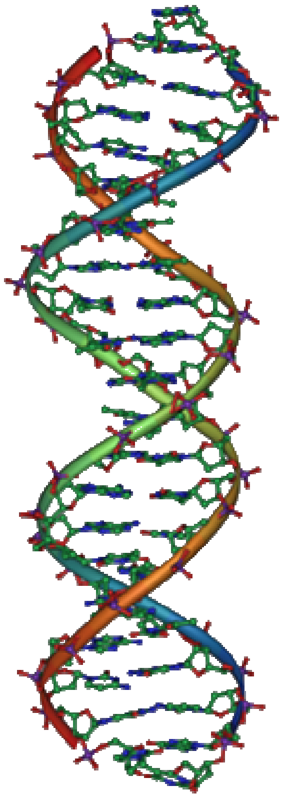

Figure 4.3 : An illustration of DNA helix (Url-27, 2008)

When nucleotides on each strand of DNA are pairing, the double helix is formed Figure 4.3. Inheritance has this physical method of copying genes by using each strand as a template for a new complementary strand. In other words, genes are codes of chemical pairs providing templates needed for production. The products in concern are proteins. DNAs form chromosomes of which 23 pairs (46chromosomes) are present in humans. The chromosomes are held in the nucleus of cells. The genetic code that the nucleotides are sequenced with is translated by cells to produce amino acids chains. These chains carry the same sequence as the nucleotides. So the amino acids forming proteins are in the same order of nucleotides forming DNA ladders (Encyclopedia Sci-tech, 2008). Proteins fold into 3D shapes in order to gain a structure to function. The folding action is dictated by amino acids. Therefore, proteins seem to be the function base for living cells and hence, the genetic code holds the basic information for life. And apparently, every cell contains the basic information for producing another human.

There seems to be a general agreement on a percentage of genes that are in the whole genome. It is 3 %. The rest is defined as "junk". The human body has an estimated number of 50 trillion cells. There is another estimation that human genome has between 2.8 and 3.5 billion base pairs. And the cells in human body have two meters of DNA (Annunziato, 2008).

Genetics is attributed to have great control of physical appearance, fitness, and behavior of living organisms. However, experiences also play a large role in the end product.

So if a succint analogy is set up between human existence and buildings, the building blocks are encoded at the designing stage, and then the cells build up during construction and the building is at its infancy when the construction is over.

There are many researches for demystifying the production processes in Nature. Stephen Wolfram, is the scientist writer of a recent book "A New Kind of Science". In his book, he tells about the long journey of his analysis of Nature's production of complex entities in a seemingly effortless process. This process seems so complex that it never reveals any notion of simplicity in its creation. However, Wolfram discovered on the contrary that nature had this complexity despite a simplicity of basic rules. He did extensive research and experimentation on whether behavior must be correspondingly simple if the rules for a program were simple. He observed a sequence of simple programs that ran systematically. What he found was that despite the simplicity of their rules, the behavior of the programs was not simple. Indeed, he observed that even some of the very simplest programs that he checked had very complex behavior. Through his observations, Wolfram came to realize that the intuition that creating complexity is somehow difficult, and requires rules or plans that are themselves complex is not correct at all (Wolfram, 2002).

Wolfram based his experimentation on cellular automata on this fundamental discovery of his on simplicity and evolution through rules. Cellular automata displays a variety of complex results created from simple forms and rules. However, the current results of cellular automata do not yet seem to explain the diversity of Nature's beings.

Architecture has adopted many concepts from Nature throughout the history. A majority of those adoptions or inspirations have served as form-finding strategies.

The morphologic approaches were deeper in the structural sense. However, scientific knowledge that humanity has come to pile up by now is richer then ever and closer to uncover secrets of producing *synthetic life*. This time, architecture has more opportunities than just creating genetic algorithms for form finding. This time, architecture can adopt material correspondence for generative design approaches. There is a chance that architects can control digital fabrication. Thus, there will be a model of digital fabrication in which the product is independent from the machines that are printing, or fabricating them.

Paul W.K. Rothemund is a senior research associate at Caltech. He brings together the study of self-assembly with DNA nanotechnology. Rothemund's work projects self-assembling devices at nanoscale. He is ambitious in figuring out how biological and chemical processes can be models as computers and execute molecular algorithms. Therefore, he developed a method of creating nanoscale shapes and patterns using DNA. DNA is used because manipulating DNA would create a model for making things.

He calls this method Scaffolded DNA Origami. He takes single-stranded DNA molecules and folds them into 2D shapes. To obtain desired shapes, he uses *oligonucleotide* strands as staples to hold the single-stranded scaffolds in space. The staple and the scaffold strands self-assemble when they come out of the synthesizer (Rothemund, 2006).

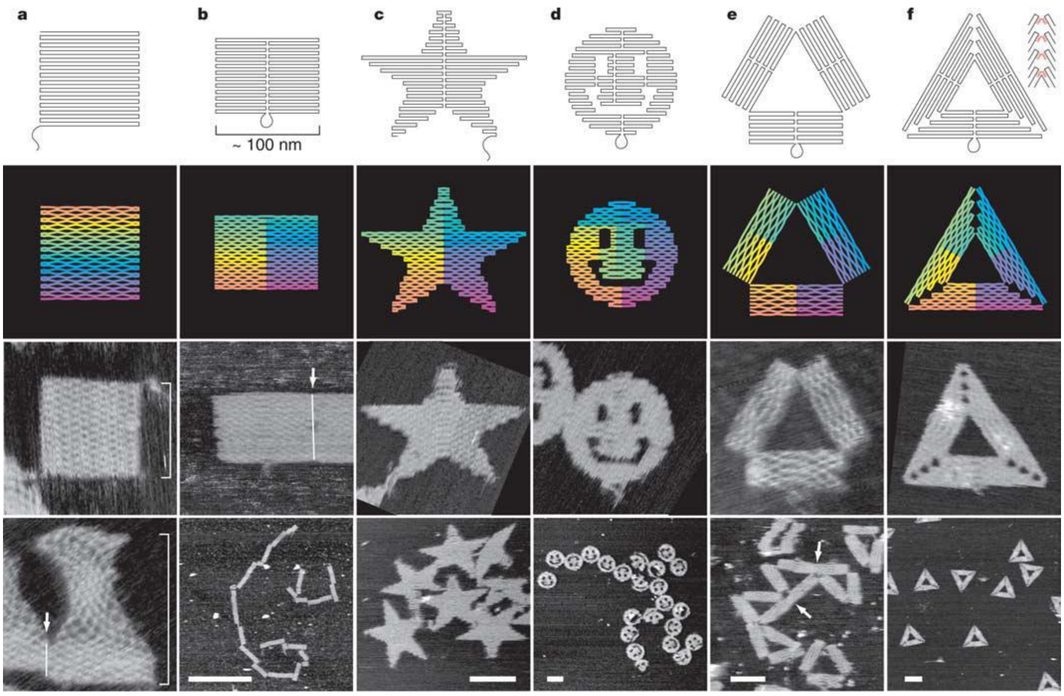

Figure 4.4 : DNA structures formed as squares, disks and five-pointed stars (Rothemund, 2006)

The obtained structures of desired shapes are around 100 nm with a spatial resolution of 6 nm Figure 4.4. This resolution belongs to the oligonucleotide strand which can serve as a 6-nm pixel. In his work, he also went further to solve the problem of producing more complex and bigger structures. He designed an exponential growth pattern for the DNA structures to form larger assemblies (Rothemund, 2008).

Dr. Saul Griffith working in materials science and mechanical engineering has researches on programmable assembly and self replicating machines at MIT. At the Center for Bits and Atoms at MIT, he proposed and demonstrated a construction with linear strings of vertex-connected square tiles. Using these tiles he folded two dimensional shapes composed of square pixels.

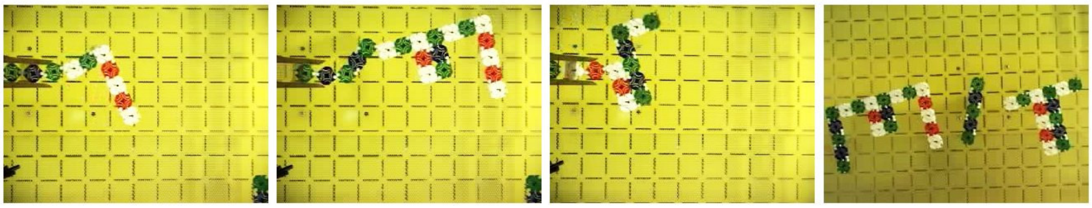

Figure 4.5 : shapes folded from a one-dimensional magnetic code-(Url-28)

First, he configured the sequence of tiles and then pushed them out. The coding of what the output will be was embedded in the materials. Therefore, the outcome is the information itself in a physical form. Four types of tiles which were magnetically patterned were sufficient for construction of any shape. To achieve MIT form (Figure 4.5) sequences of the four file types were patterned. A 3D version of this construction was also achieved based on voxels and edge connections. This work leads to a conclusion that a manufacturing system of two component tiles with seven states for each could realize self-replication of 3D structure by copying and folding according to the encoded sequence (Url-29, 2004).

4.3 Transform Follows Transfunction:Third Possibility: Both 0 And 1

In the future, space can be instantly transformable. In that way, manufacturing of materials and fabrication of building components might become one same process. In a concept of buildings that are capable of instant transformation, there is a notion of transfunction entailed with the former quality. The state of being either one thing or another is what kept things from being instantly transformable. With a growing understanding of the quantum theory, means of constant transformation may be achieved. Furthermore, the difference between form and function will vanish while transition is in progress.

4.3.1 Quantum and Molecular Mechanics In Brief

Material properties like hardness and strength or whether it is a solid or liquid is determined by their reactions to forces that are applied. A material is a solid if its molecules resist coming closer to each other. If they resist but still let small forces to move through, then it is liquid. Therefore, if the molecules are loosely bonded and spread apart then it is gas.

Molecular mechanics accepts atoms as objects that are subject to some molecular forces. There is a small attraction between atoms called the van der Waals force. There is another force created by gain and loss of electrons, which is called the ionic force. This gain or loss of electrons of atoms creates an electrical charge. The ionic force is stronger than the van der Waals force. The other force is created by covalent bonds of atoms and causes them to keep much closer together in a springy fashion. The whole existence and manner of forces and bonds are called a *force field.*

The quantum realm is yet quite bizarre to understand and uncover. Humans are used to thinking about the material world and percieving existence at macro scale. Perception of waves are bound to their knowledge of sound in air or what they see on the surface of water. However, in the quantum world, things can be described with both types of existence. Thus, an electron can be considered as an object while it has presence in two different places at the same time. This property is called superposition of states. Superposition is the property that quantum computers utilize for computing several calculations at the same time (Hall, 2005).

4.3.2 Object of Transformation

Up until this stage, it became obvious that Nanotechnology is based on the concept of tiny, self-replicating robots. Digital fabrication as molecular manufacturing brought about an inevitable notion of disassembly or recycling as an important issue to be solved. Therefore, in the context of this thesis, matter is no longer considered as individual objects. Indeed, it is a constant organization of molecules at the atomic or sub-atomic scale. So the output is actually a constantly transformable entity whether it be a product or a building.

There is a similar concept called the Utility Fog (Figure 4.6) envisioned by J.Storrs Hall. He envisioned stuff filling the air like fog. Utility Fog consists of a mass of tiny robots.

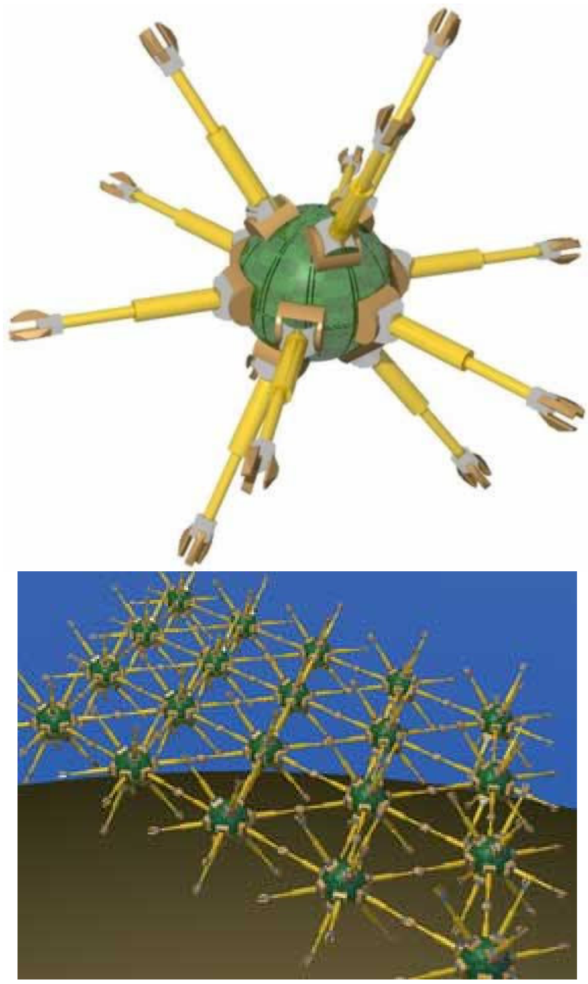

Figure 4.6 : Utility Fog (Hall, 2005).

The tiny robots form a lattice by holding hands in 12 directions. Arms of the robots are relatively long and thin compared to their bodies and they are telescopic. Although heavier than air, the Fog is programmed to simulate its physical properties, so you can't feel it: when you move your arm, it flows out of the way. To see, there would be holographic eyephones to wear. A car can be made of Utility Fog, and can be changed with a new one that is to say a new organization every day. A house can be patterned to be anything, including a computer-generated illusion. Therefore, Utility Fog can become a transparent interface between cyberspace and physical reality (Hall, 2005).

4.3.3 Works of Architectural Approach

The British architect John Frazer, is both an educator and a writer on architecture and intelligent CAD systems and the writer of the influential book *The Evolutionary Architecture*. The book was published in 1995 simultaneously with an exhibition of the same name at the Architectural Association in London. The exhibition demonstrated their research on basic form-generating processes in architecture. The concept of evolutionary architecture in his context suggests Nature's evolutionary model as the generative process for architectural morphology. In this context, architecture is a form of artificial life created due to evolutionary processes and interactive in the sense of responding to changing environments (Frazer, 1995).

An Evolutionary Architecture explores the artificial life concept by starting off with a code script resembling DNA's and then exposing the core information to developmental and evolutionary processes. Therefore, the goal of this approach is to simulate Nature's behavior in the built environment. The Evolutionary Architecture models itself with direct emulation of an organism carrying the fundamental design process of nature.

As a recent project pursuing natural concepts in architectural morphology, Frazer adopted another concept called Autotectonics. He set up a group called Autotectonica. The group is defined as committed to the idea of constant development in new approaches to the evolution of sustainable systems. Autotectonics comes from the Greek auto – self, and tektonikos – pertaining to construction.
Thus, the term refers to a notion of self generating, self organizing, and self sustaining evolving systems. Autotectonics aims at empowering creative minds to create and manipulate their own environments. This concept offers a creative process in interaction with the designer which then evolves with the users or the inhabitants in under the natural conditions of the environment. Autotectonics, according to Frazer, forms the basis for a new form of design education besides being a way of thinking, living and of acting (Frazer, 2008).

John M. Johansen, in the late sixties, declared that he was concerned with processes rather than passionate forms and masterworks of architecture. He envisioned the building as an organism where structure is determined by process. Buildings, in his imagination are self-organizing, self-regulating structures with the capability of self-diagnosis and self-healing and with a central nervous system.

In his definition of a new species of architecture, he describes the process of his organic architectural structures as follows:

> *" I place a "seed" artificial DNA, blueprints for what my house will be. Planted, as in earth, the roots reach down to nourishment for its upward growth, as molecules replicate and vastly multiply" (Johansen, 2002).*

He writes a diary of the imaginary owner of a "molecular-engineered house" during its construction in 2200. In the ninth day of the construction, owner of the house moves in with his family Figure 4.7 – 4.8. The construction starts with an excavation for placing large vessels he calls “assembly vats”. The second day, the vats, and ingredients (chemicals and materials in liquid forms) are delivered and placed on the site, thereby pumping the ingredients into vats. There comes “The Code” in day three. He describes the code as a representation of a very old combination of architectural drawings, specifications and strategies of construction management. The code is placed in the vat. The fourth day is when molecular growth begins. A vascular system is developed with roots germinating from the mixture in the vat and reaching the ground level. The roots (also beams of ground floor) then start forming a superstructure by weaving a ground floor platform by extending themselves across each other. The structure grows during the fifth day by extending its vertical ribs and forming necessary lattices of the structure. He also mentions that a neural network joins the structure at this phase. During the sixth day the boundaries of molecular-engineered house start functioning mimicking membranes of living cells. When membranes receive electric current molecules disengage and exterior membranes open while letting inhabitants permeate the house. The seventh day is for the growth of interior finishes that are shortly called as “body support”. The next day brings us an artificial, organic shelter which Johansen refers to as a cocoon. Day nine is the grand opening: The house is a flexible, molecularly engineered, self-sufficient living space which can be rearranged or demolished and recycled (Johansen, 2002).

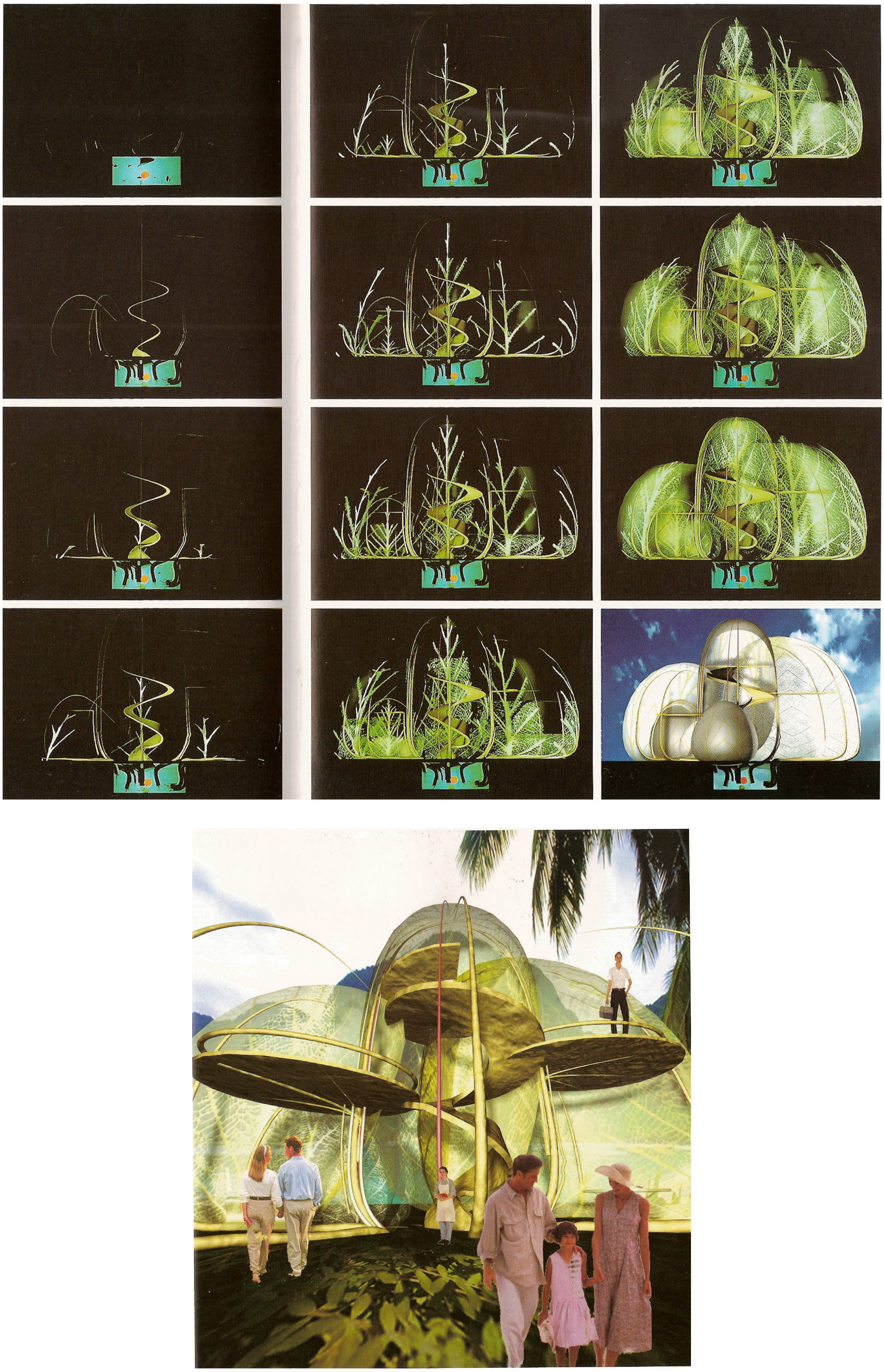

Figure 4.7 : The Growing House- Molecular-Engineered House (For the Year 2200), (Johansen, 1998).

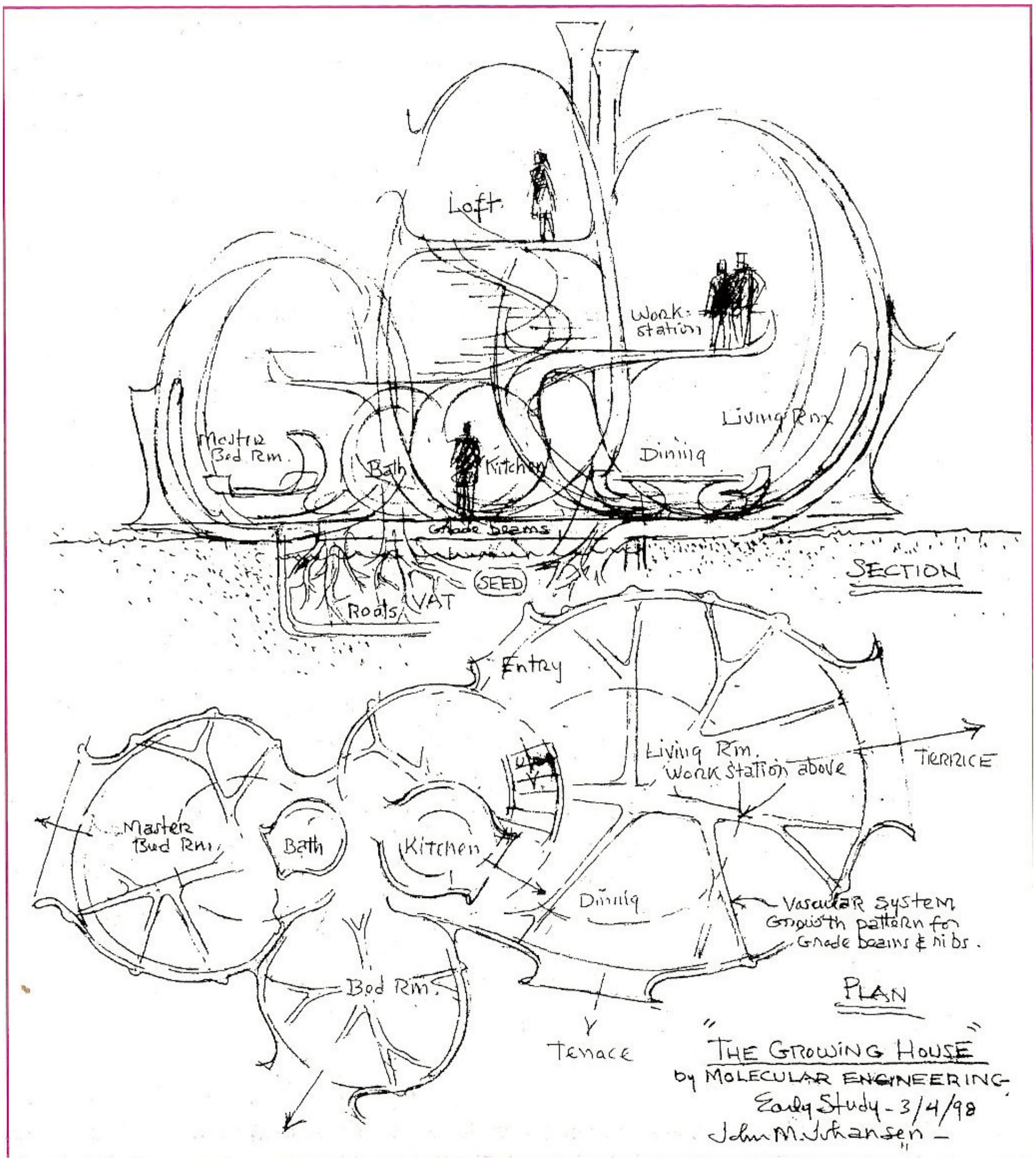

Figure 4.8 : The Growing House- Plan and Section, Early drafts, John M. Johansen, 1998.

Another concept of growth for buildings titled “Fab Tree Hab” (Figure 4.9) is introduced by the architect Mitchell Joachim. The concept envisions growing houses from trees. This concept works at macroscale with prefabricated scaffolds set up for natural plants to cling and grow on and around. The bodies of trees, are the load-bearing structure, and the branches make the lattice frame for the walls and roof. Prefabricated scaffolds manipulate growth of plants in the early stages. The tree home is designed to be edible for food supply to some organism other than human inhabitants. The tree also produces food for human inhabitants in exterior walls and gardens.

Figure 4.9 : “Fab Tree Hab” by Mitchell Joachim.

The architect envisions a construction site with live trees instead of dead timber. The tree house is designed to be self-sustaining an in harmony with the environment. It is anticipated that the house will conform to the environment that it grows in.

Growing buildings are a common ideal for many. However, concepts differ in scale and expectations. Creating a live building or an inorganic building mimicking life do have challenges to overcome if possible at all. However, once it is achieved, the next issue will be to keep it alive (Url-30, 2006).

4.4 Living But Not Dying

Self-recovery and self-management of buildings are general concepts that are already being realized in the sense that smart buildings perform for their inhabitants. Immortality, however, is beyond being smart. Buildings and other inorganic *organisms* can be self-sustaining thus capable of sourcing their own energy and managing its sources. They may also be capable of self-recovery. However, immortality requires a constant cycle of sources and motives for living. An immortal kind of building has a reason and a design for being. Therefore, it does not emanate through manufacturing or fabrication but through growth, thus transformation and recovery.

This is a scenario for an immortal kind of building. This type of a building does not pass away but it transforms and transfunctions. The immortality in concern resembles the notion of Singularity to some extent. The Singularity is defined as the technological creation of intelligence that is smarter than human. Singularity is a term defining a state when humans become almost immortal by unifying with robotic technology, thus becoming transhuman. This endeavor also aims at carrying AI to the point of bringing about immortality for even living creatures.

An immortal building will have a reason for being which is coded right at the beginning of its existense. The code will let it function in a generative manner and the building will build itself as in *growth*. The building will then start functioning for its inhabitants. Therefore, in the long term, functional needs of inhabitants and any other environmental input will signal an urge for the building to transform and transfunction. That is when immortality comes to the scene. The building that is able to change its essence in terms of form, function and material properties will never cease to exist. It will never need a dematerializer. Thus, it will be instantly reprogrammed either by its own AI or by the designer/user through interpretation of new situations that arise.

5. CONCLUSION AND RECOMMENDATIONS

The major purpose of this thesis is to make a forecast on the future of architectural design, thus, what architecture may evolve into within the context of interdisciplinary technological developments.

With the main focus being on manufacturability of things and constructability of buildings, the thesis analyzes ways that architectural execution may evolve through within the impact zone of rapidly developing technologies. Therefore, there is a fictive nature to the evolution in concern within the scope of the thesis. Advancements and experimentations in sub-atomic fabrication are addressed in order to reveal the issues that may be on the verge of morphing the profession of creating spaces, i.e. architecture.

The thesis does not put forward a certain model created with molecular manufacturing as the necessary means are not handy yet. Rather, it is an effort on preparing a ground and a theoretical construction site for future architectural experimentation. The technology mentioned throughout the dissertation is not entirely achieved yet. However, as explained in necessary chapters, the advancements that have been envisioned for a 20 to 50 years ahead are expected to be realized. It seems to be a matter of time, commitment and social consensus. Therefore, the achievements that are expected will draw huge differences between the parties that have them and the ones that don't. One reason for this is the exponential pace that most new technologies are improving at. The other reason is that the nature of these technologies create paradigm shifts in areas they serve for. Nanotechnology has already caused great changes in top-down approach. Smaller volumes of space became smarter thereby changing ways of delivering function and service in many goods as in textile industry or medical applications. The bottom-up approach will cause greater change and create greater probabilities in both terms of idea and matter.

These technologies do come with their drawbacks along with their merits. However, perils are not addressed in the thesis as they belong to another domain and are not influential in the way they might affect architectural creation processes in the case of molecular fabrication.

Another expectation of great changes is quantum computing. Information processing at very high speeds will cause huge differences. Achieving quantum computing technologies will probably lead to new possibilities for processing information or materials.

In the final chapter of the thesis, a fictive scenario for immortal buildings is revealed in order to describe what new technologies may bring about. Instant shifts between materiality and immateriality may be the most fictive part of the scenario. However, that is where the advancements in concern do lead. Smart molecules that are smallest robots with embedded artificial intelligence that know when or where to grow and when to stop are main characters of this scenario.

Currently, technological advancements have not yet reached a level to create an instantly transformable kind of architectural execution. A subject of this sort requires extensive research with interdisciplinary teams by gathering various expertise. The goal of such a research may reach the end but does not necessarily need to do so. Most space explorations do not meet their goals. However, the advancements that are achieved during research create great influenced on life on earth.

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