PRINTING THE VERNACULAR

3D Printing Technology and its impact on the City of Sana'a, Yemen

BY KYUNGSIK KIM

B.A. Architecture
Hongik University 2012

Submitted to the department of architecture in partial fulfillment of the requirements for the degree of Master of Architecture at the Massachusetts Institute of Technology
Feb 2016

Signature redacted

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ABSTRACT

This thesis project is a speculative proposal; it assumes that 3D printing technology is a major manufacturing and construction method in the future.

The industrial revolution that has begun in the 19th century was the transition to a new manufacturing process. This transition included going from hand production to machine production and eventually changed the entire way of making things, buying things, moving things, and etc. The changes of our life led to the transformation of our cities. Current cities were formed based on the Industrial Supply Chain that enables flow of materials and products from supplier to customer. This supply chain decided locations of factories, retails, roads, ports, warehouses, and etc that have structured cities.

In recent years, 3D printing has attracted increasing attention. The prospect of printing machines has inspired enthusiasts to proclaim that 3D printing will bring "the next industrial revolution", while others have reacted with skepticism and point to the technology's current limitations. However, 3D printing could proliferate rapidly over the coming decade. Improvements in speed and performance could enable unprecedented levels of mass customization, simplified supply chains, and even the "democratization" of manufacturing as consumers begin to print their own products.

Although there has been a number of studies on the 3D Printing technology itself and its impact on economy, less attentions have been paid to its spatial impact or impact on our cities. As the industrial revolution transformed cities, 3D Printing is expected to change our current cities in many ways, as it will change the way of making, moving, buying things again. The fact that 3D Printing can be done near the point of consumption, implies several possible scenarios of future cities

This thesis illustrates different degrees of influence of the technology in the city of Sana'a, Yemen. The city has four distinct areas currently: the historical world heritage site, a partially protected area, a modernized area, and an informal settlement. The four distinct areas will be changed in different ways by different uses of 3D printing technology.

The tower house, which is one of the most significant building typologies of the city, is used to examine and compare the influences of the technology.
More specifically, the ornament of the tower house and possible scenarios of transformation are the main design focus of the project. Ornament will appear in different scales and configurations in the future city of Sana'a, from high resolution ornament to inhabitable ornament.

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ACKNOWLEDGMENTS

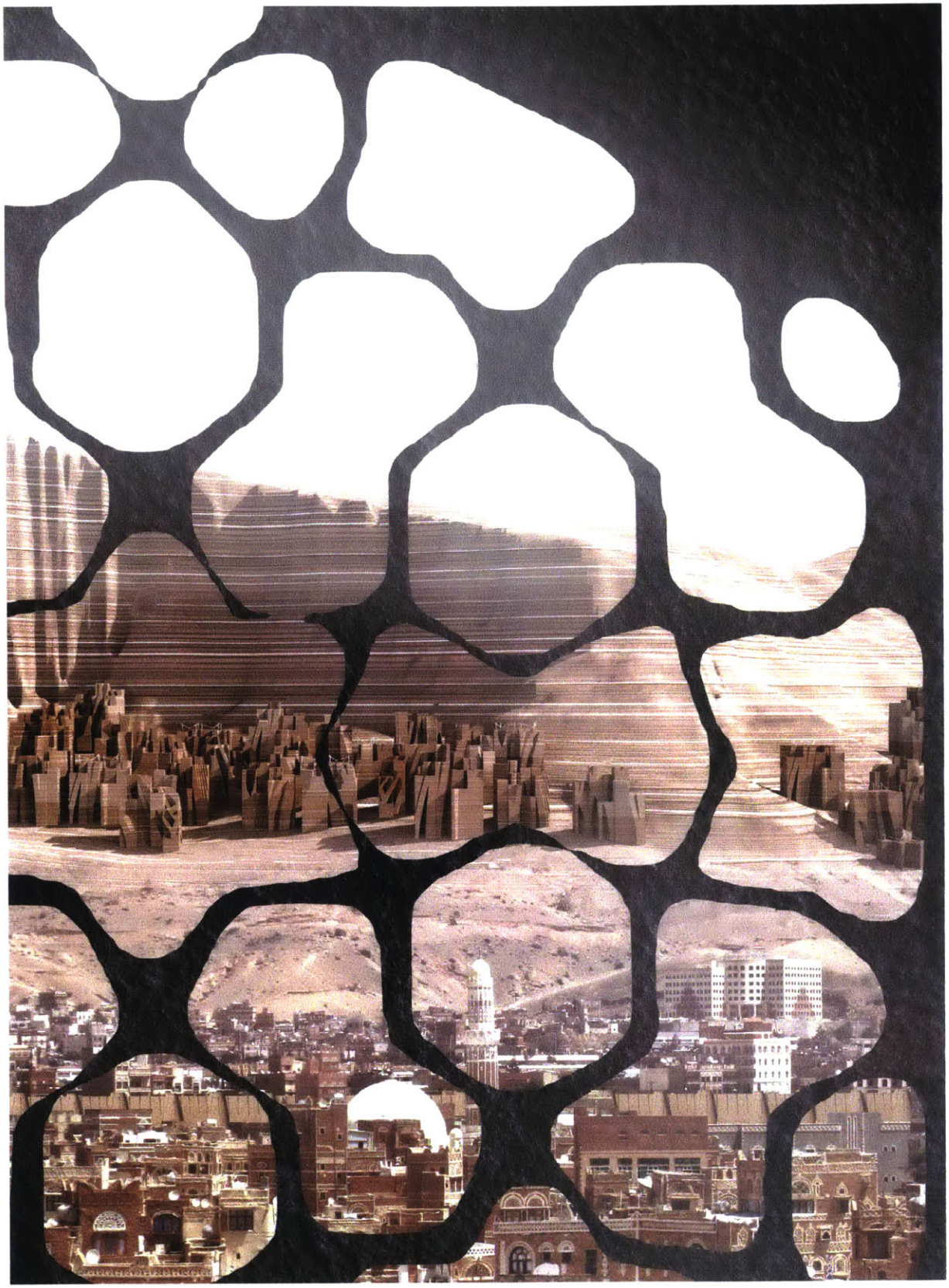
First of all, I sincerely thank the faculty members and my colleagues at MIT. It was a great pleasure to work on the thesis, learning from many others.

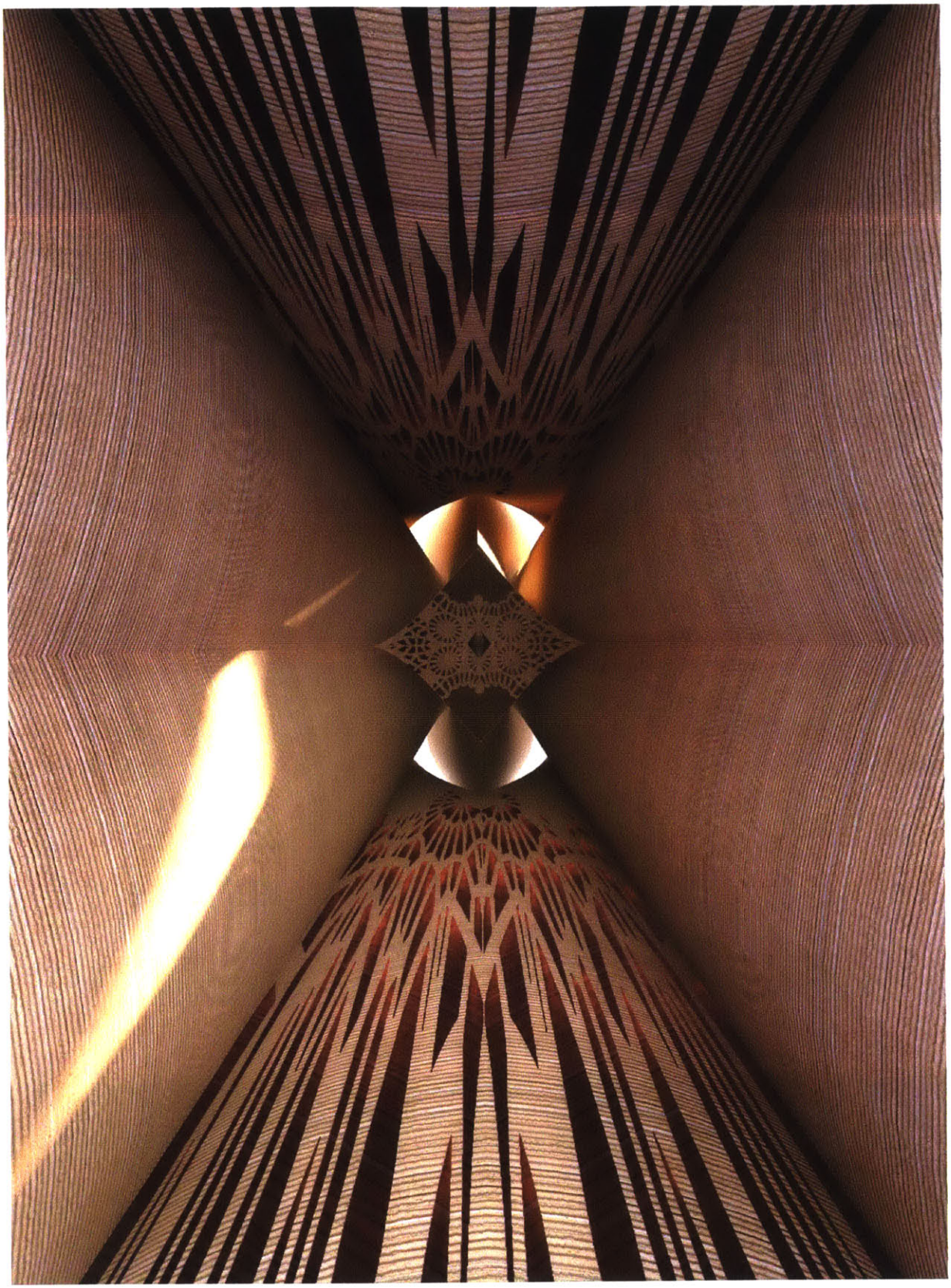
To Anton, for your commitment to education above all else and for knowing what I myself did not. Your acute criticism was a true inspiration and it is something that will stay with me for many years to come. The way I think about architecture will never be the same.

To Liam, your criticism at direction came at the most important times, the project would have not been the same without you.

To James, for your insightful thinking and broad reference giving me so many inspiration not only for this thesis but also for my thinking in architecture and art in general.

I also want to note the fact how much I appreciate the infinite support from my parents and family.





I. FEATURES OF 3D PRINTING TECNNOLOGY

I-1. 3D PRINTING AND TRANSFORMAATION

Technology And City

Product And City

Motor And City

Re-Organizing City

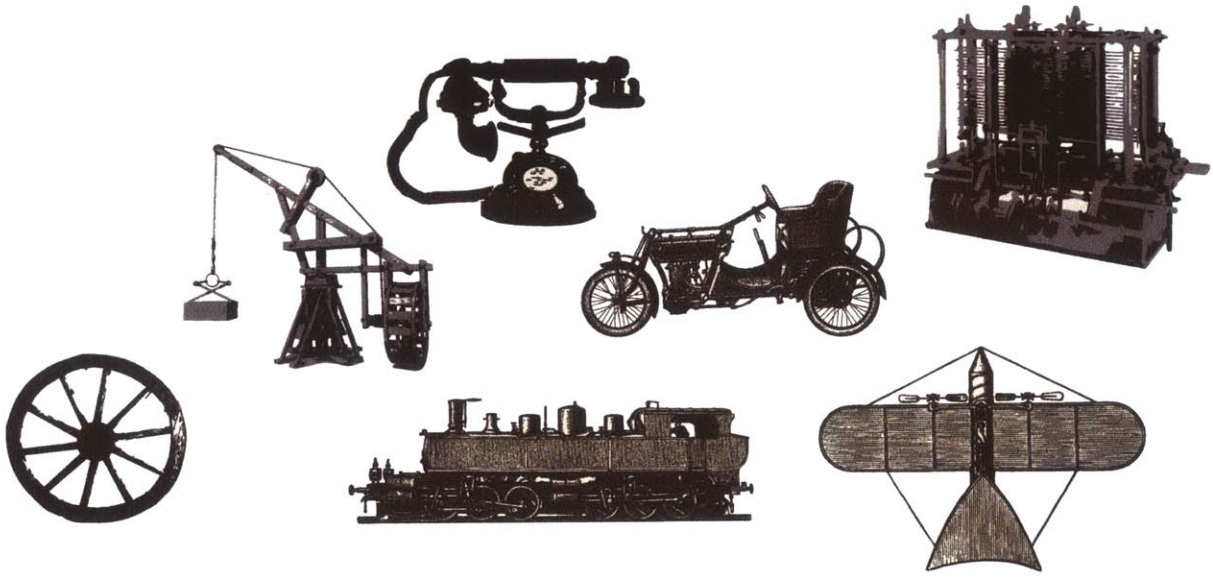
Re-Authenticity

Re-Programing City

Re-Constructing City

Re-Ornamenting City

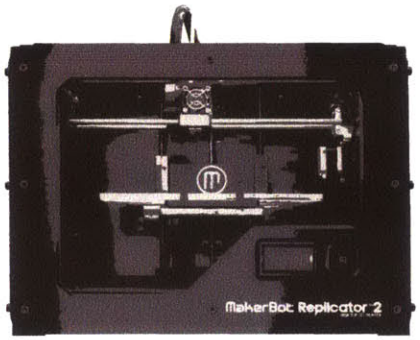
Left_"The Creative Machine" exhibition



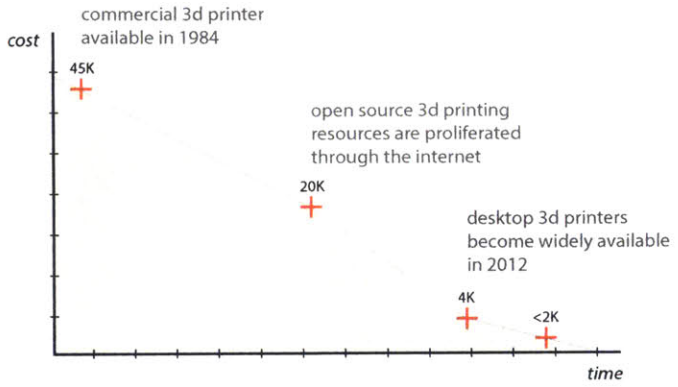
WHEEL	*CRANE*	*STEAM ENGINE*	*COMMUNICATION*	*AUTOMOBILE*	*AIRCRAFT*	*COMPUTER*
Mesopotamian	*Ancient Greek*	*Jerónimo de Ayanz y Beaumont*	*Alexander Graham Bell*	*Karl Benz*	*The Wright Brothers*	*Alan Turing*
The wheel is probably the most important mechanical invention of all time. Nearly every machine built since the beginning of the Industrial Revolution involves a basic principle embodied in this inventions.	The archaeological record shows that no later than c.515 BC distinctive cuttings for both lifting tongs and lewis irons begin to appear on stone blocks of Greek temples.	A steam engine is a heat engine that performs mechanical work using steam as its working **fluid.** Using boiling water to produce mechanical motion goes back over 2000 years, but early devices were not practical.	The invention of the telephone is the culmination of work done by many individuals, the history of which involves a collection of claims and counterclaims.	A car is a wheeled, self-powered motor vehicle used for transportation. Most **definitions of the term** specify that cars are designed to run primarily on roads, to have seating for one to eight people, and to be constructed for the transport of people.	Two American brothers, inventors, and aviation pioneers who are credited with inventing and building the world's **first successful airplane and making the first** controlled, powered and sustained heavier-than-air human **flight, on December 17,** 1903.	An Enigma machine was any of several electro-mechanical rotor cipher machines used in the twentieth century for enciphering and deciphering secret messages. Enigma was invented by the German engineer Arthur Scherbius at the end of World War I.
c 3500 BC.	**c 515 BC.**	**1606**	**1876**	**1886**	**1903**	**1903**

TECHNOLOGY AND CITY

Technological inventions have been influencing the structure of cities throughout history. The invention of a wheel, for instance, enabled the network of streets, expanding the limit of a city further away. Current cities have been formed based on the industrial supply chain that was invented to make products most economical way. This changed the entire structure of cities, shifting the mode of manufacture from hand to machine production.



COST OF ADDITIVE MANUFACTURING

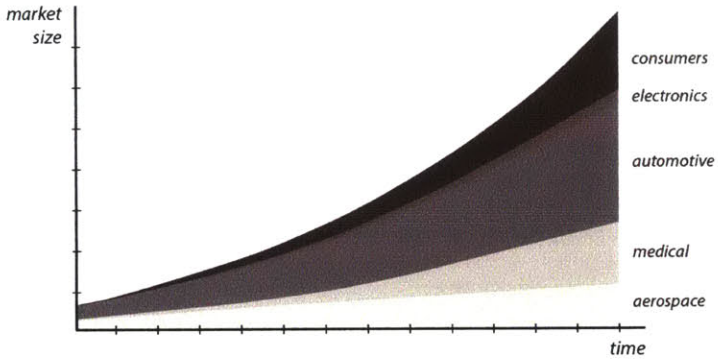


GROWTH OF ADDITIVE MANUFACTRING

3D PRINTER

Chuck Hull

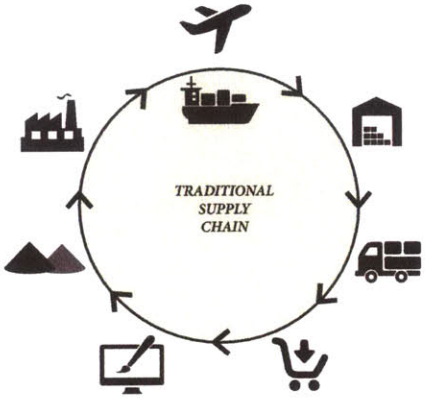
3D printing (or additive manufacturing, AM) is any of various processes used to make a three-dimensional object. In 3D printing, additive processes are used, in which successive layers of material are laid down under computer control.
These objects can be of almost any shape or geometry, and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot.

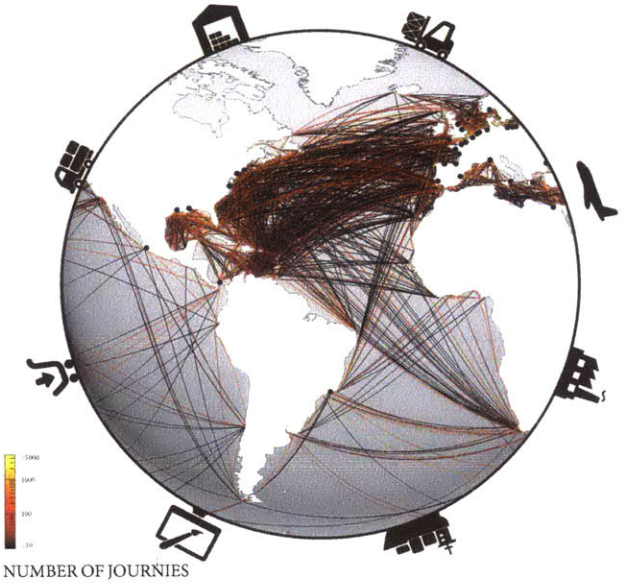


1984

However, the recent invention of 3D printing technology is believed to change our cities again as it will modify the way of making, moving, and buying things. The fact that 3D Printing can take place at the point of consumption implies total collapse of the supply chain.

CURRENT SUPPLY CHAIN



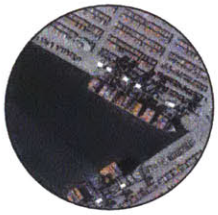


NUMBER OF JOURNIES
OF CARGO SHIPS

Current cities were formed based on the Industrial Supply Chain. It enables flow of materials and products from supplies to customer. This supply chain generated factories, retails, roads, ports, warehouses, and etc. that have structured our current cities.

SUPPLY CHAIN & CITY ELEMENTS

MAKE

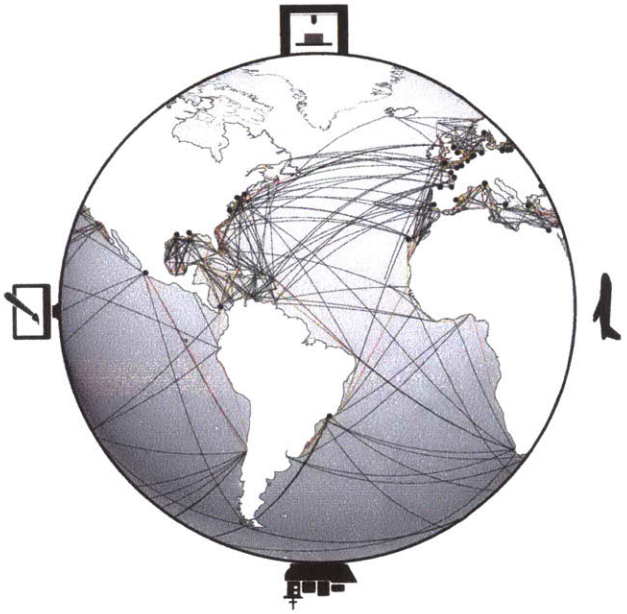


MOVE

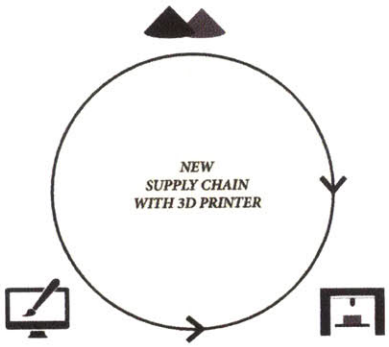
BUY

CURRENT SUPPLY CHAIN

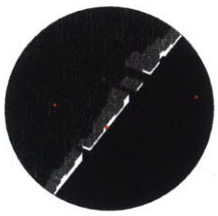
The industrial revolution that has begun in the 19th century was the transition to a new manufacturing process. This transition included going from hand production to machine production and eventually changed the entire way of making things, buying things, moving things, and etc. The changes of our life led to the transformation of our cities.



NEW SUPPLY CHAIN

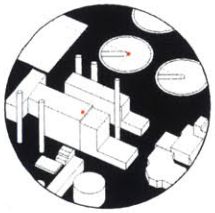


NEW SUPPLY CHAIN & CITY ELEMENTS



MAKE

MOVE



BUY

In recent years, 3D printing has attracted increasing attention. Improvements in speed and performance could enable unprecedented levels of mass customization, simplified supply chains, and even the "democratization" of manufacturing.
The New Supply Chain is the clue for future city transformation. The fact that 3D printing can be done near the point of consumption implies several possible scenarios of future cities.

3D PRINTER AND NEW SUPPLY CHAIN

Localized printing hubs and individual 3D Printers will take over the manufacturing functions in the future, replacing current factories and decreasing cargo freight movements.

PRODUCT & CITY

Researching the way of production throughout history clearly explains the way a city is structured. As society continued to evolve and industrialized, the way of production became more and more complicated. Today, the process of manufacture requires a number of different places and travels all over the world, from mining raw materials to delivering to retail stores.

However, 3D Printing will disrupt the current process of manufacture: We will purchase a digital file of a product and print it either at home or at a printing hub depending on the size of a product. This can signify that we are returning to the state of craftsmen. And we will be participating not only in production of information but also in materialization of the digital information.

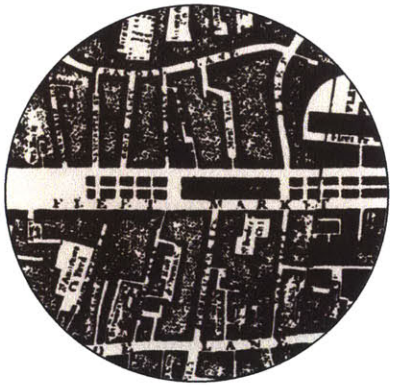
PREHITORIC

Cave

DOMESTIC

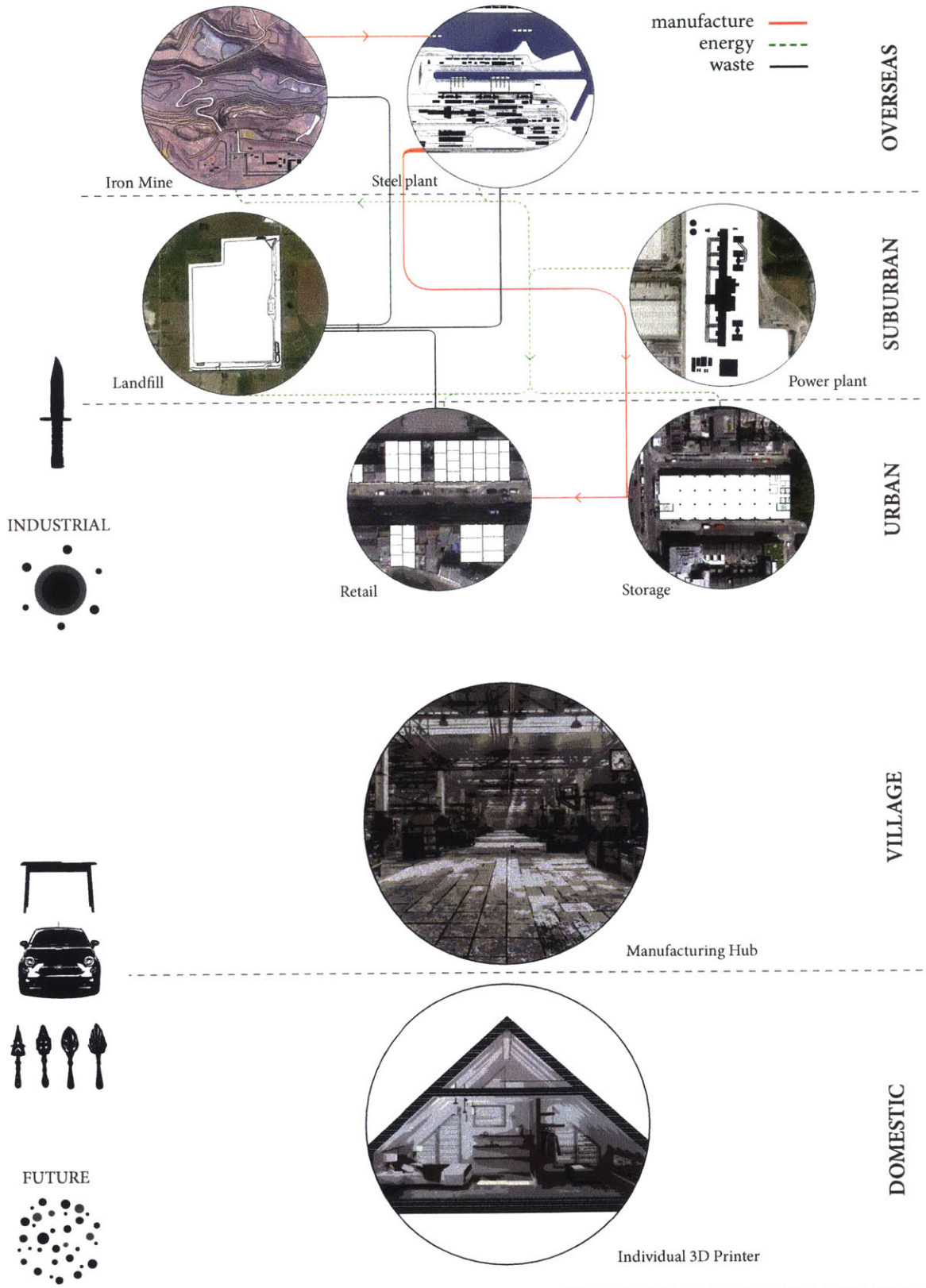
MEDIEVAL

Forge



Market

VILLAGE


manufacture
energy
waste
OVERSEAS
SUBURBAN
URBAN
VILLAGE
DOMESTIC
Iron Mine
Steel plant
Landfill
Power plant
Retail
Storage
Manufacturing Hub
Individual 3D Printer
INDUSTRIAL
FUTURE

Evolution of Ford

1903 — 1912 — 1928 — 1965 — 2003 — 20XX

Emblem first used on Model C

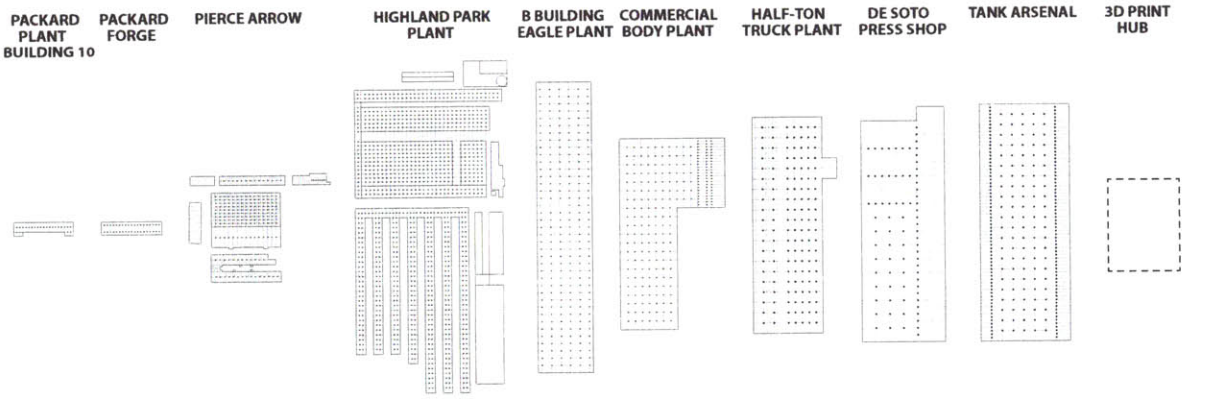
First use of an oval as a trademark

Ford script in oval, **first seen on Model A**

Ford Oval established as corporate sigmature

Dimensional oval created to represent the company and the brand

Evolution of Assembly Plant & Automobile



1903 — 1905 1906 1910 1911 1926 1932 1935 1936 1937 1940 — 1956 — 1965 — 1968 — 1976 — 1986 — 1997 — 2003 — ?

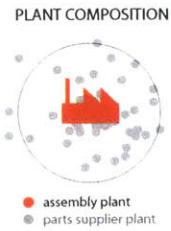
MODEL A | MODEL T | V-8 TUDOR SEDAN | DELUXE CONVERTIBLE | THUNDERBIRD CONVERTIBLE | MUSTANG | FAIRLANE TORINO | TAURUS | EXPLORER | 3D PRINTED CAR

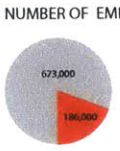
MOTOR & CITY

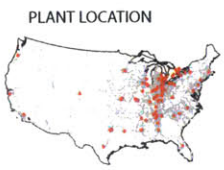
More specifically, comparing the current and the future manufacturing system of Motor industry gives better idea of how future cities will evolve. The current system requires a number of supplier plants besides one main assembly plant, necessitating deliveries between plants.

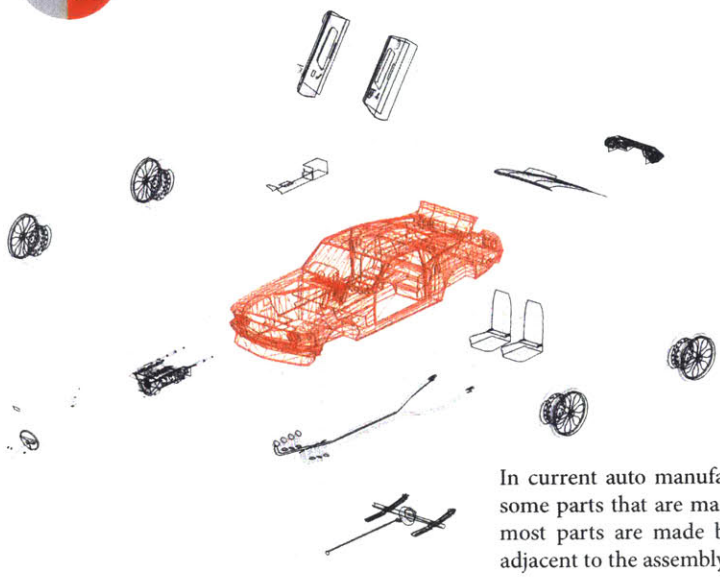
However, the future system by 3D Printing Technology will be much simplified; more and more components will be able to be printed at one place, making the system much concentrated.

Current Auto Manufacturing System



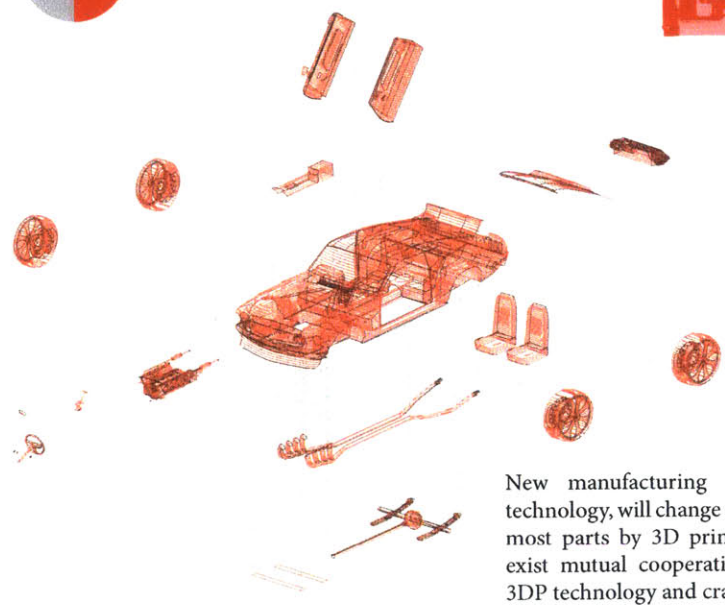






In current auto manufacturing system, there are some parts that are made at assembly plants and most parts are made by suppliers which locate adjacent to the assembly plants

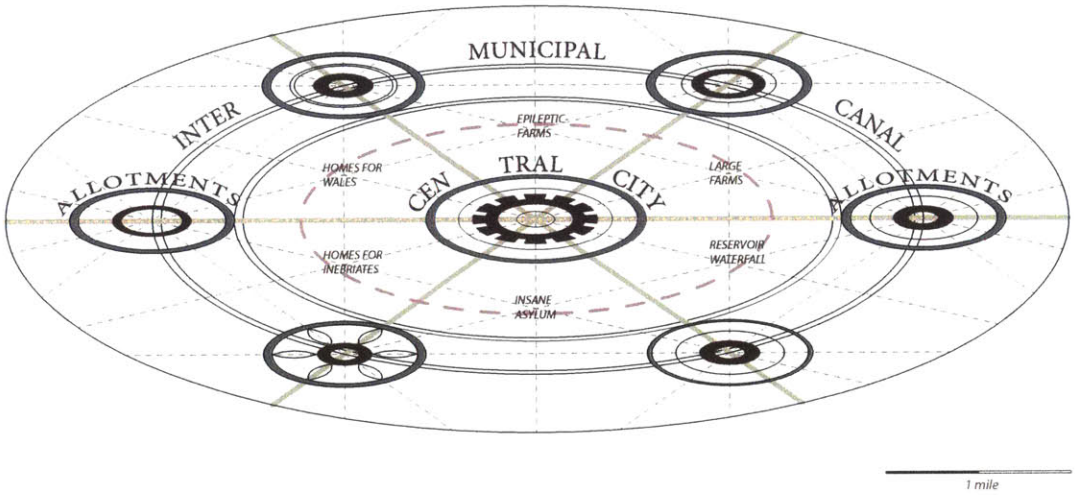
New Auto Manufacturing System by 3DP Technology



New manufacturing system, aided by 3DP technology, will change current system by printing most parts by 3D printers. However, there will exist mutual cooperation and conflict between 3DP technology and craftsmanship

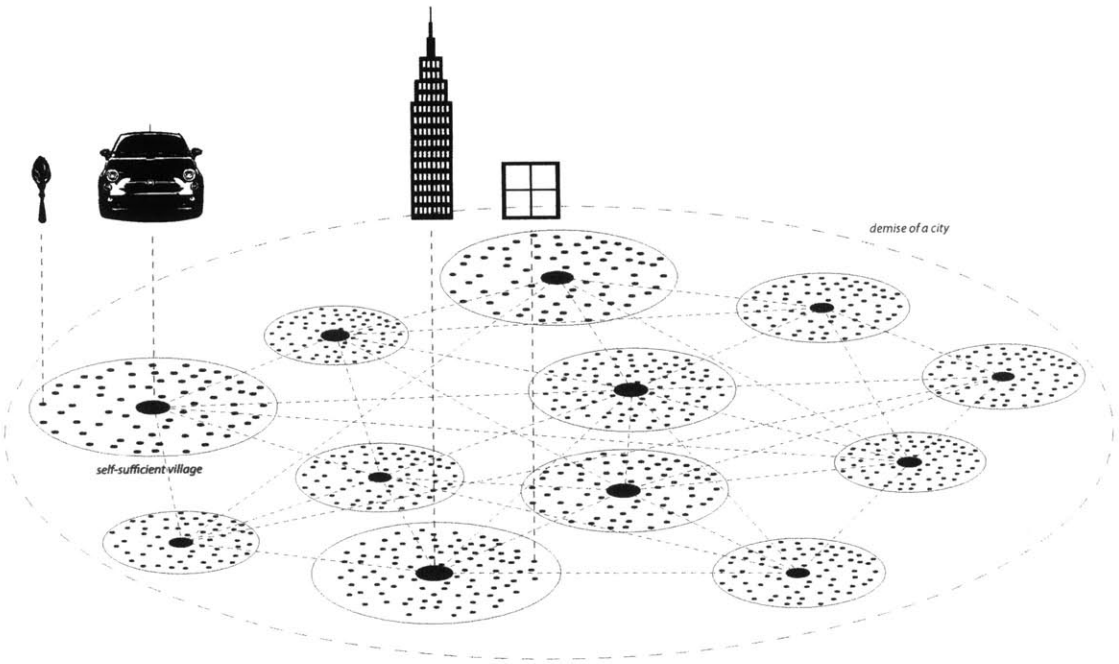
Garden City

Ebenezer Howard



The garden city would be self-sufficient and when it reached full population, another garden city would be developed nearby. Howard envisaged a cluster of several garden cities as satellites of a central city of 50,000 people, linked by road and rail.

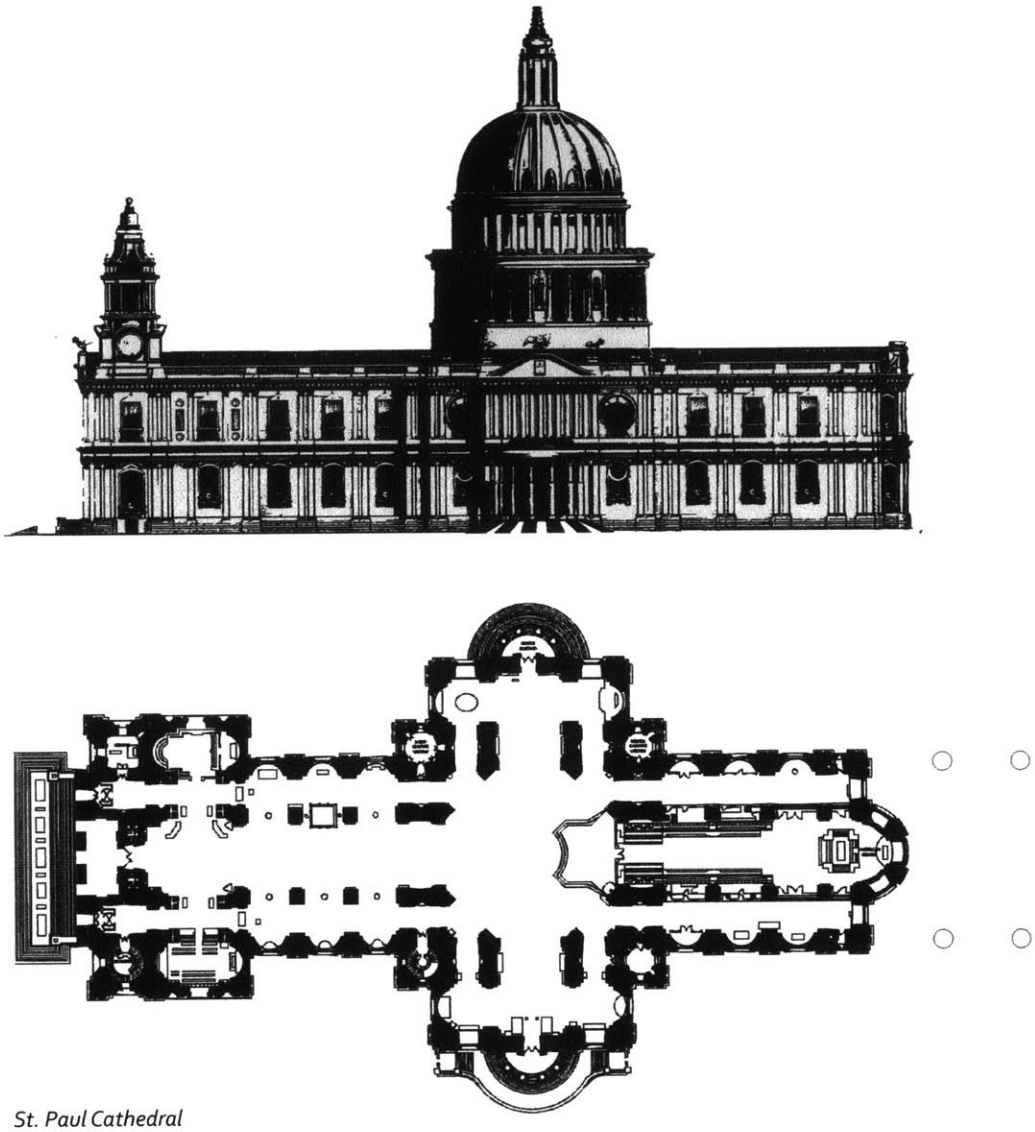
Future City



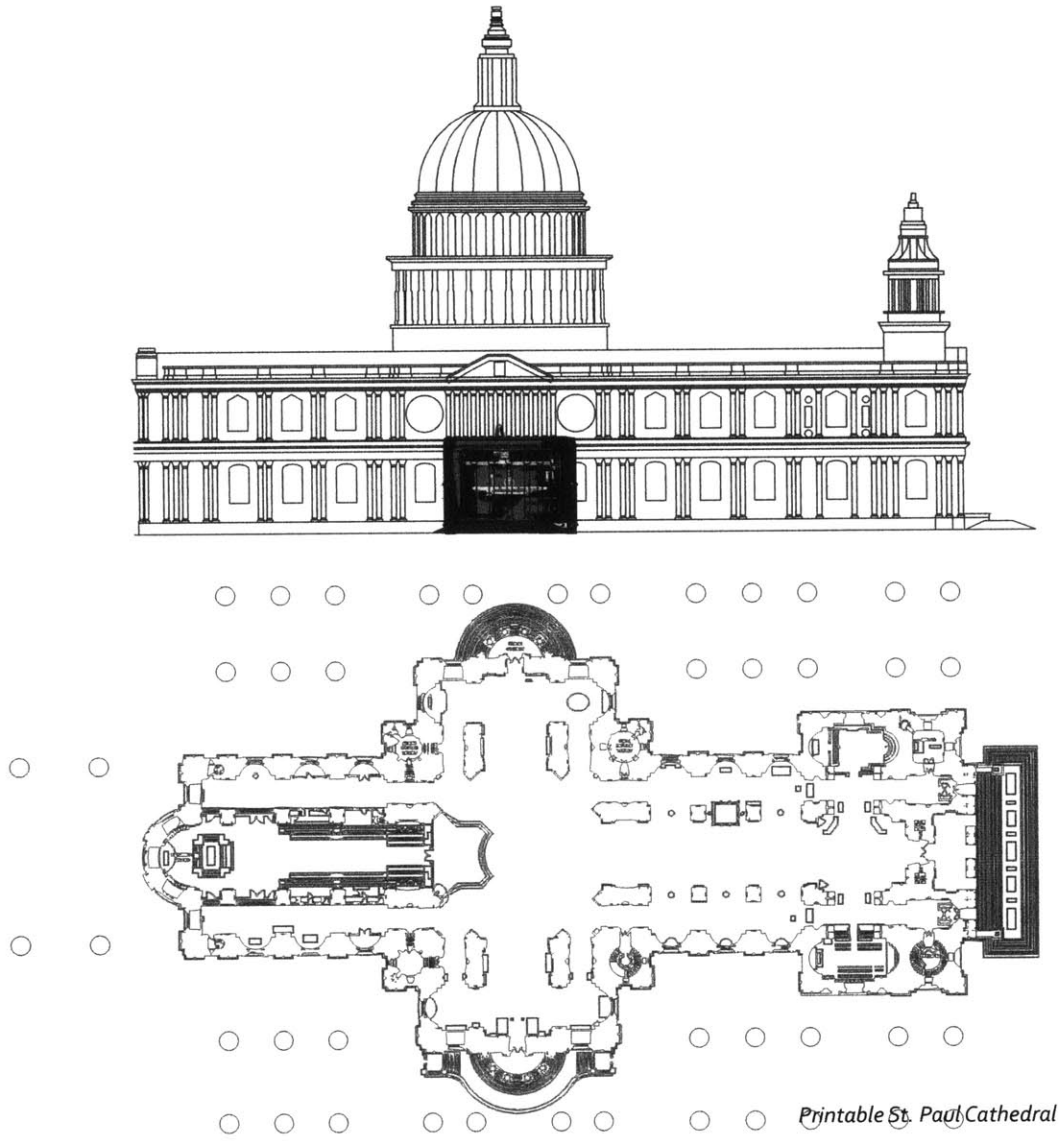
Future cities will consist of multi territories without hierarchy. The center of each territory or village could be a large scale printing hub, whereas the rest are individual houses that are able to produce small scale product.
This might lead to demise of city since large, shared infrastructures are no longer needed, as each village are becoming more self-sufficient.

RE-ORGANIZING CITY

Change of manufacturing mode leads to the re-organization of a city. Unlike the industrial city that has a center and sub-centers under a strong hierarchy, the future city is expected to have less hierarchies. It will consist of multi-territories that have a center inside and each territory will be self-sufficient. Based on this theory, it can be argued that the center of each territory or neighborhood will become a new manufacturing hub for larger products, whereas smaller products will be printed at home.
However, 3D printing brings up an issue regarding "what is original or authentic". As the technology will become more sophisticated, things we are printing might not be able to discern from their original. This will lead to another questions such as "what needs to be preserved or protected and how it can be implemented?", which might also influence the way a city is organized.



St. Paul Cathedral



Printable St. Paul Cathedral

RE-AUTHENCITY

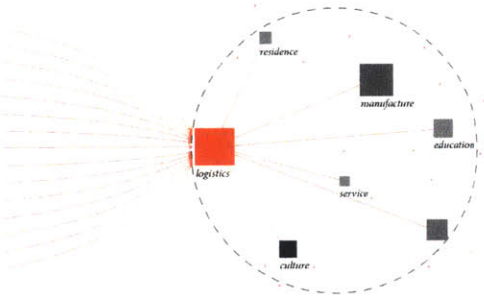
From a small toy to a magnificent building, 3D printing will be used to produce in a faster, cheaper and much efficient way. When a 3D printer can print almost anything, it will bring up a question of "what is original or authentic?"

As we print more and more things in a high quality, the importance of authenticity will become more critical, which might influence on the organization of a city as well. It will also bring an issue of "what does conversation mean in the new city?"

1951
the UPS Foundation
Jim Casey established the UPS

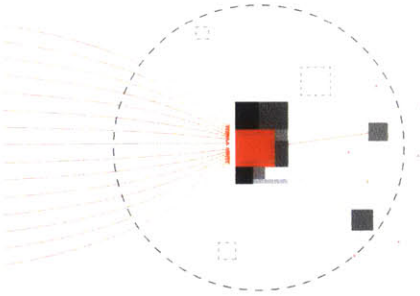
Demise of Logistics?
or Emergence of the New

Jul 31, 2013
the UPS Store, San Diego
UPS initiated 3D Printing Service



Logistics and Manufacture in Current Cities

In current cities, logistics industries function as distribution of materials and goods to different parts of cities.
The location of logistics industries are optimized in order to minimize the transportation fees, thus in important traffic points

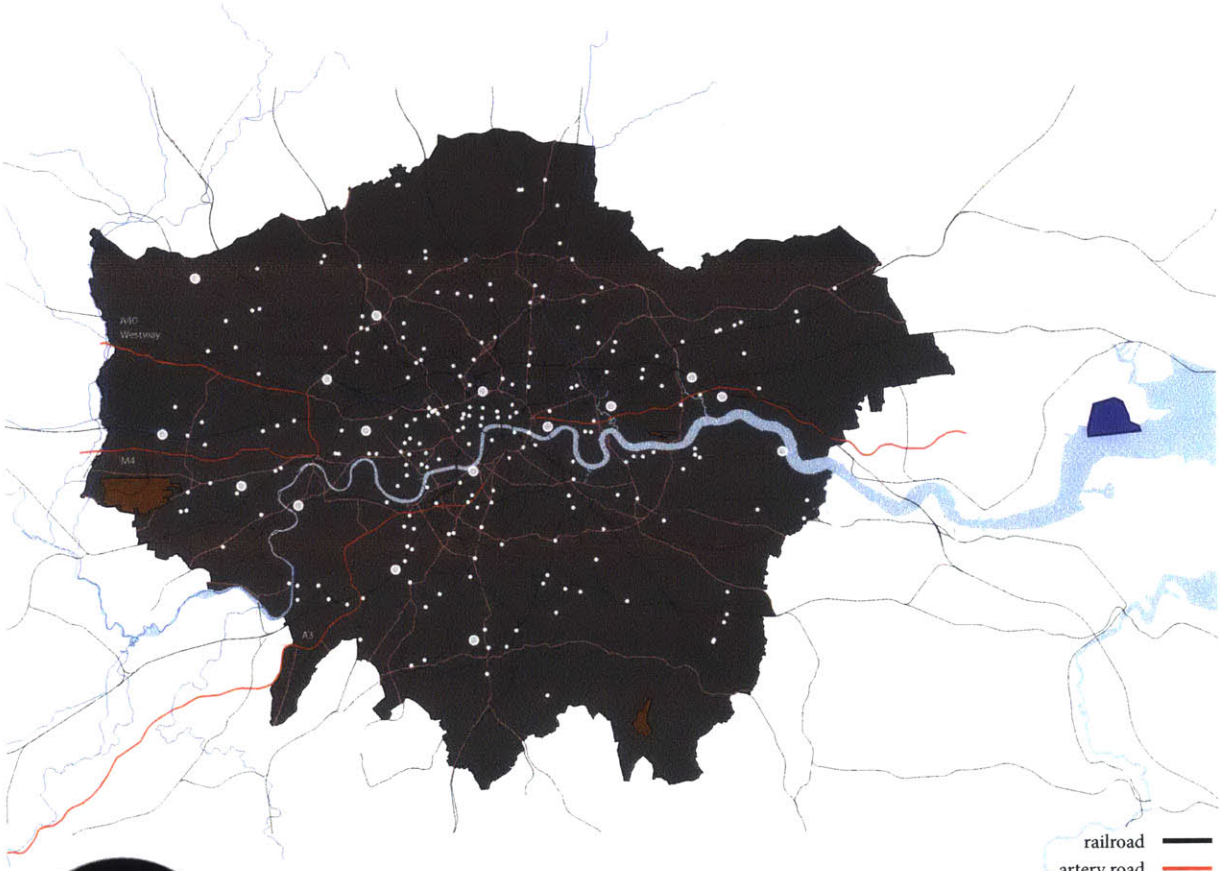


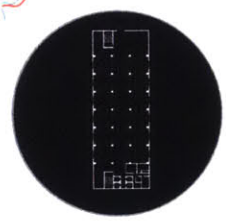
Emergence of New Place in Future Cities

It can be speculated that logistics facilities will replace some parts of manufacturing facilities, which might lead to attract more functions such as markets, plazas, and even cultural spaces. This new type of "Place" that is hightly concentrated, efficient, and accesible will be a place both as a logistics hub as cultural and social hubs in the future city

RE-PROGRAM CITY

As a more practical approach, I am paying attention to the fact that logistics companies such as UPS recently initiated 3D printing services. Realizing the crisis of logistics caused by 3D printing technology, UPS rather attempts to merge itself with new manufacturing industry. In this situation, it can be assumed that the logistics hub, merged with manufacturing functions, will make a new type of place which contains unprecedented combination of different programs, such as manufacture, logistics, market, station, and etc. and this will attract more public programs. And unlike the fact that manufacture industry has been causing conflicts with its neighborhoods in the past, the new place will rather work as a medium that enhance the life of a community.
This proves that 3D printing in the future will threat the logistics industries by significantly simplifying supply chain.. Consequently, logistics companies rather attempt to merge them with other industries, implying many possible changes in cities.





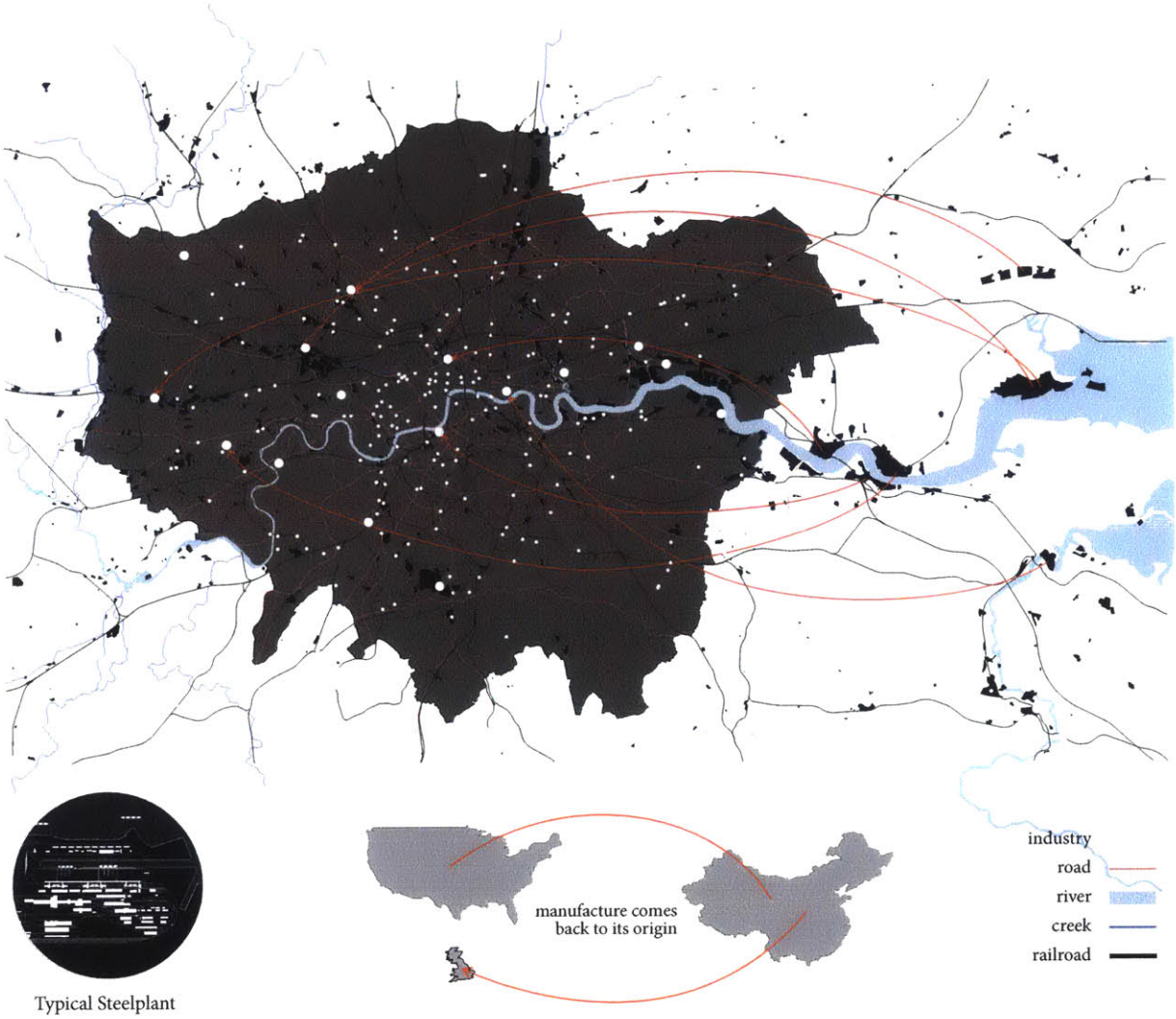
Typical Storage for
Logistics Industry

Freight Links

Passenger Links

Logistics Hubs

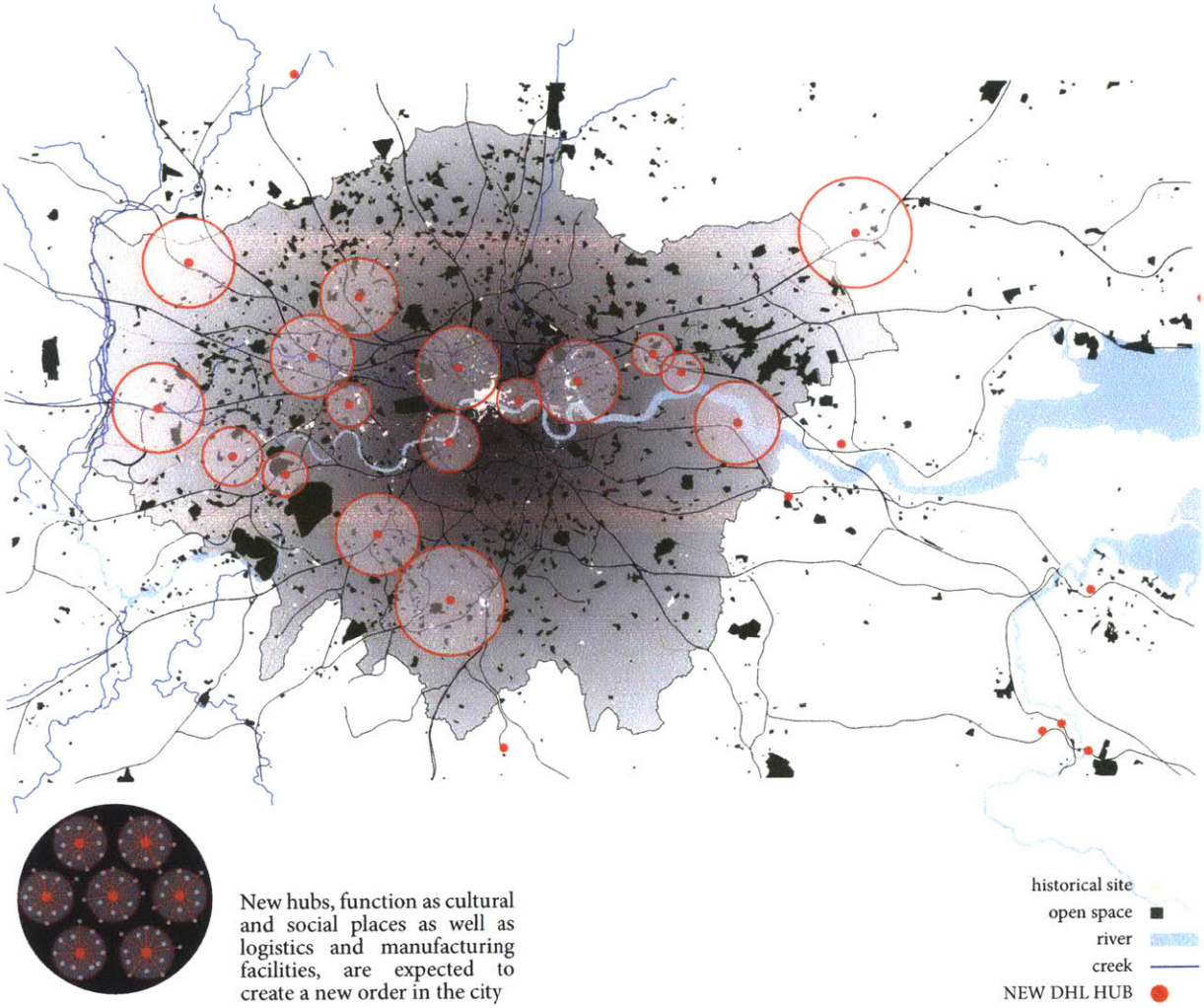
In current London there are dense networks of a number of service points for logistics companies, such as DHL. Service points consist of company HG, offices, storages, and etc.
The are tightly connected with different transportation modes including shipping, road, railroads, and aircrafts.



Typical Steelplant

Industry Back to City

Since the industrial revolution, London has been transformed into an industrial city and the number of industrial facilities drastically increased until mid twentieth century.
However, as London is turning into a post-industrial city, heavy industries have been moving out of the city, while light industries are still remaining inside. And the location of those facilities are largely depending on transportation modes, such as river, roads, and railroads.
As industries move out of the city, costs for logistics increased.



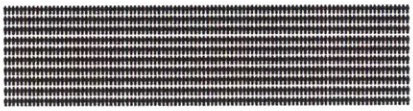
NEW DHL HUB
_new "place"

New hubs, function as cultural and social places as well as logistics and manufacturing facilities, are expected to create a new order in the city

Logistics Hub as a New "PLACE"

If logistics facilities will be replacing manufacturing factories, what would this cause to the city? Will this lead to attract more functions such as markets, plazaz, and even cultural spaces?
If so, will the city have a new type of "Place" that is hightly concentrated, efficient, and accessible?
Will logistics hub function as cultural and social hubs in the city?

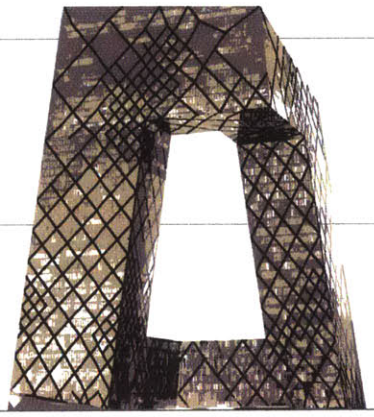
The Great Pyramid Giza

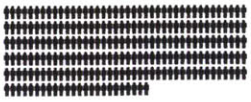


100,000

20 yrs(2580-2560BC)

China Central Television HQ

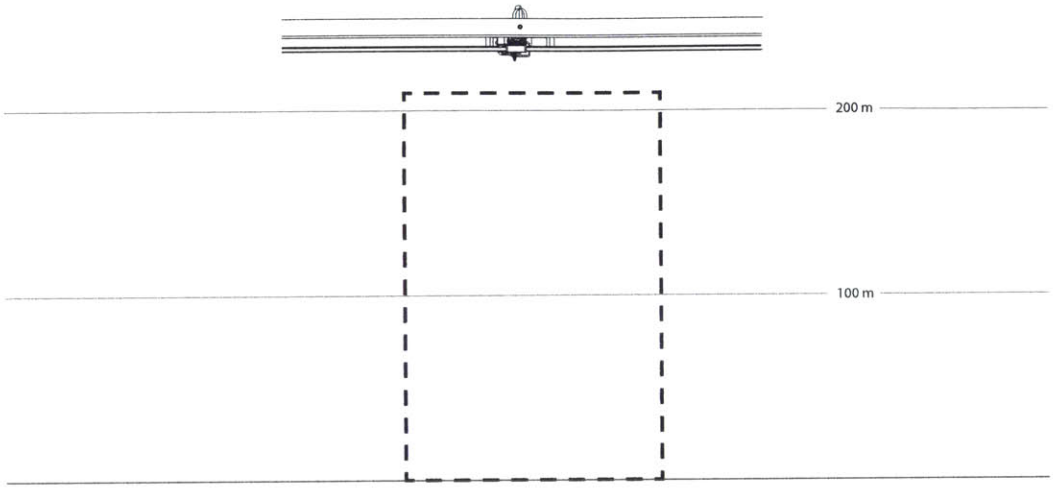




3,400

8 yrs(2004-2012)

3D Printable Building

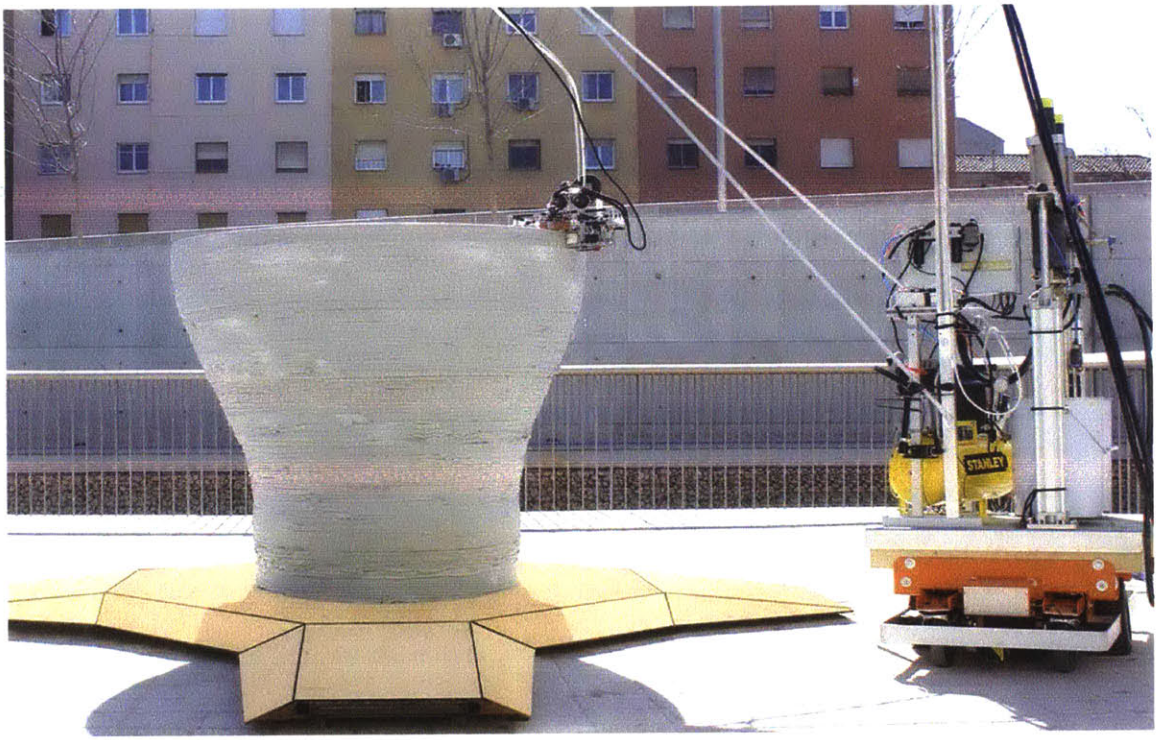


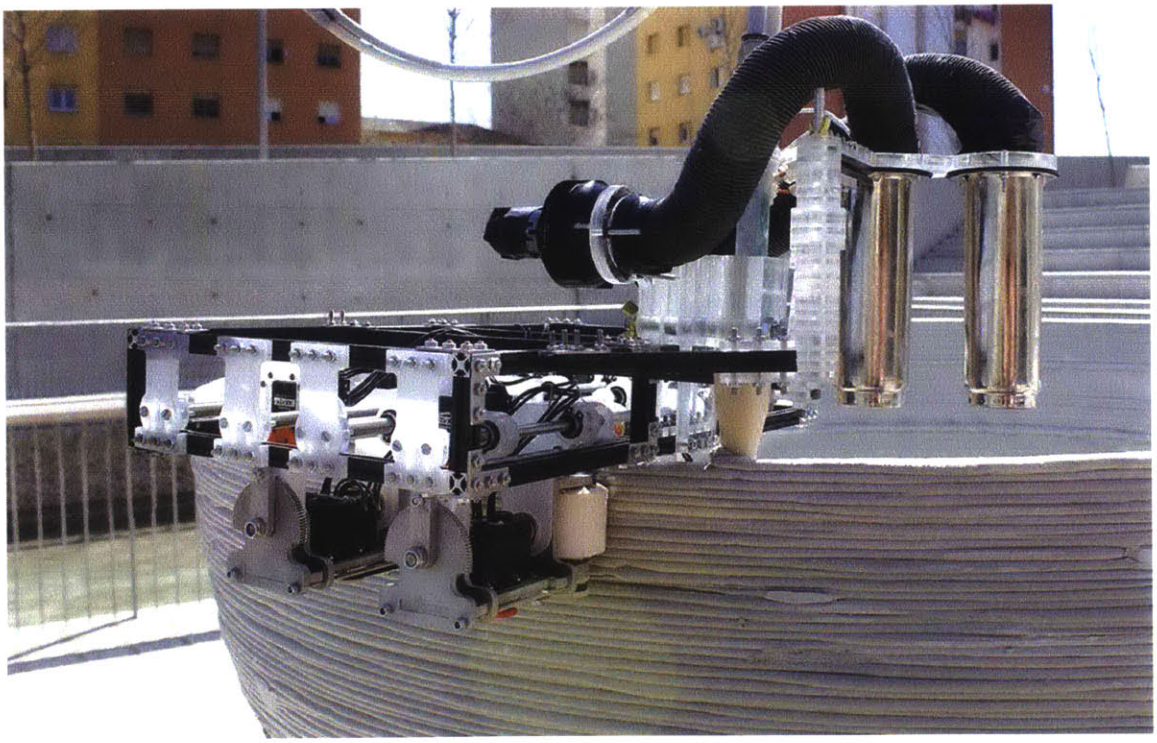
Labor(100 ppl)

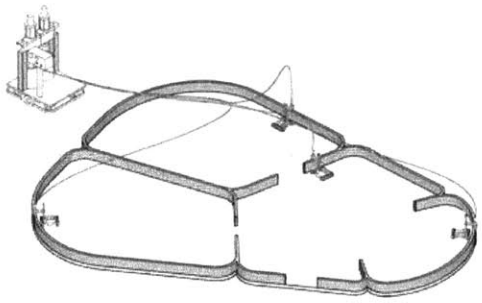
Construction
Duration (1yr)

RE-CONSTRUCTING CITY

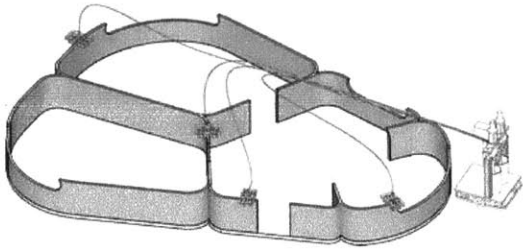
As 3D printing technology makes a major way of construction in the future, it will entirely change the notion of construction; labor and time.
Compared to the way buildings had been constructed in the acient times and current days, a 3D printer will no longer need a number of construction labors and long period of time. In terms of the number of labor it requires, it will need someone who prepares building materials and the others who run the machine.
Moreover, when it comes to the construction time, it will greatly decrease the amount of time needed as the technology is being improved now and in the near future.


STANLEY

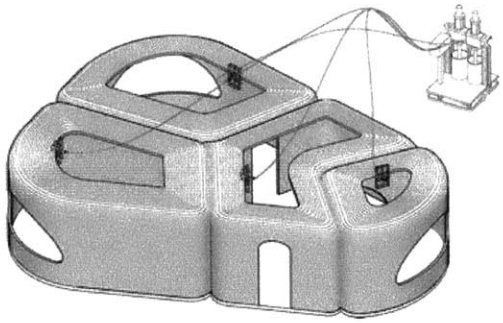




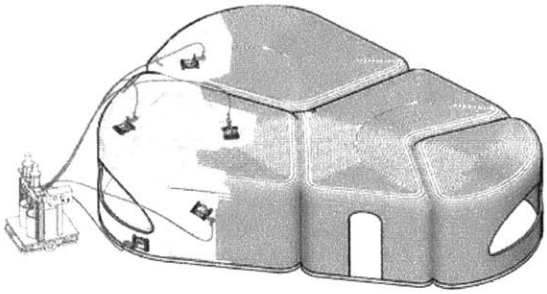
Footprint-One or more Foundation Roborts make the footprint; first 20 layers of the structure. They can move according to a predefined path continuously or back and forth. Small robots are connected with pipes to the supplier robot, that feeds the printing materials.



Wall-After the base is done, Grip Robots are clamped onto the footprint. They extend the structure furture by printing layers of material meanwhile holding onto layers they previously printed. Their nozzle shift from side to side allowing to create curved walls.



Ceilings-The grip of these robots is strong enough and the curing speed of the material is fast enough to use them for horizontal printing. These robots can print ceilings and window/door lintels.



Reinforcement-To reinforce the shell vacuum robots attach onto it and print additional layers over it. These layers don't have to be parallel to each other and be applied only where structure requires them. Vacuum Robots can travel over surfaces of any inclination.

MINIBUILDER

Minibuilders are a new series of mobile 3D printer robots that can assemble large structures on site. Developed by Petr Novikov, Saša Jokić, and a team of designers from the Institute for Advanced Architecture of Catalonia (IAAC) in Barcelona, Spain, the Minibuilder concept offers the possibility of freely printing 3D structures that are far larger than the printers themselves.

RE-ORNAMENTING CITY

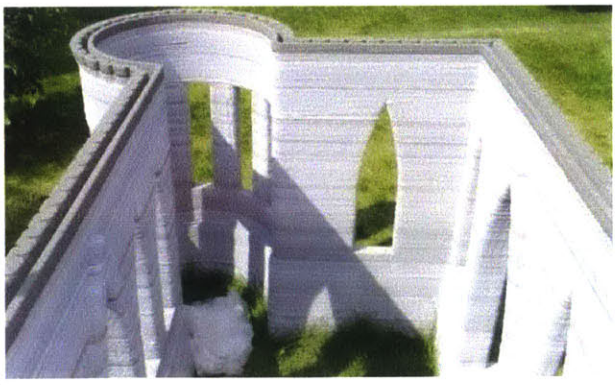
From its way of construction, 3D printer creates inherent ornament; Layer and Fill.
As it adds layers of material on top of each other, it creates subtle stratification which becomes an aesthetical aspect. Moreover, the way 3D printers resolve solid space is to generate a default pattern, which is strong enough to support structurally. By changing default pattern and having a series of different patterns that can be exposed to surface, it makes another kind of ornament.

LAYERS

layers of material creates
subtle differences

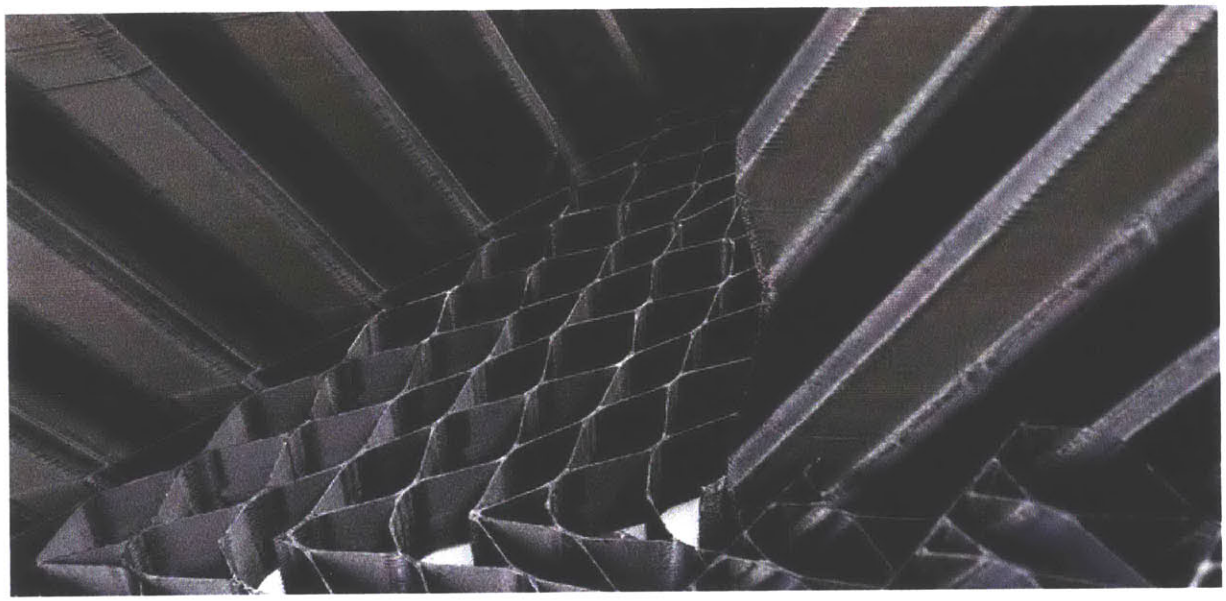
Clay Printing

3D Printed Castle



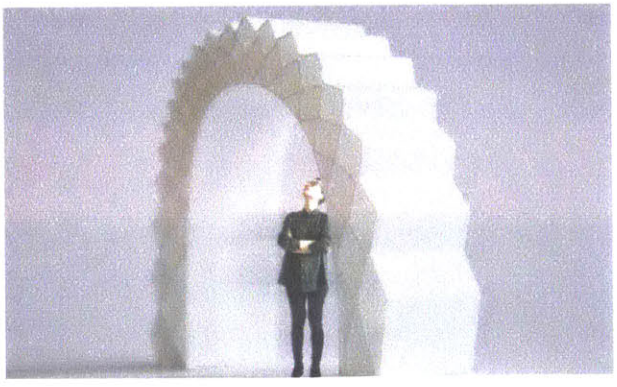
FILL

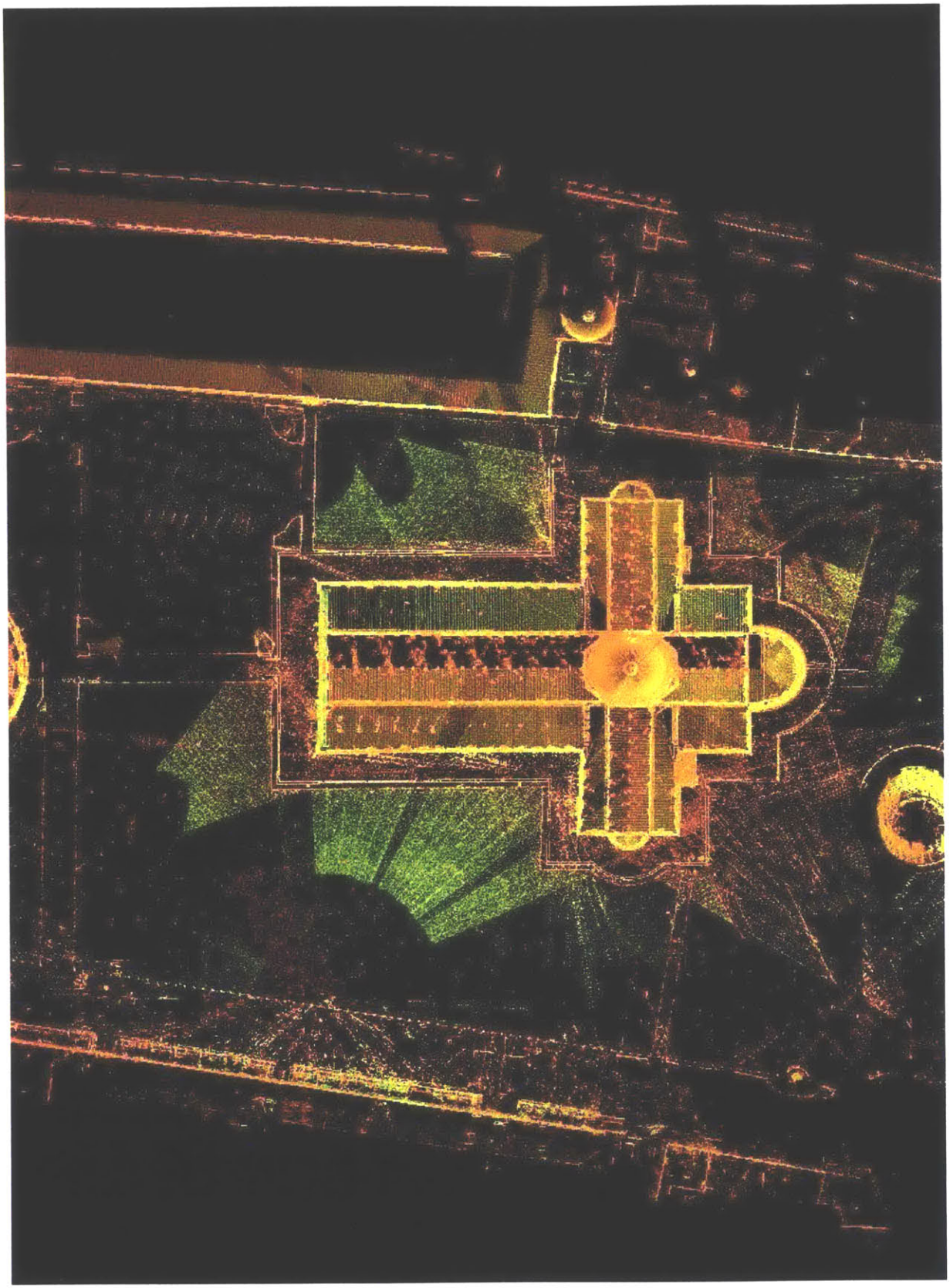
3d printers creates fill in order to resolve solid space, which can become new ornaments from the technology



Clay Printing

3D Printed Castle



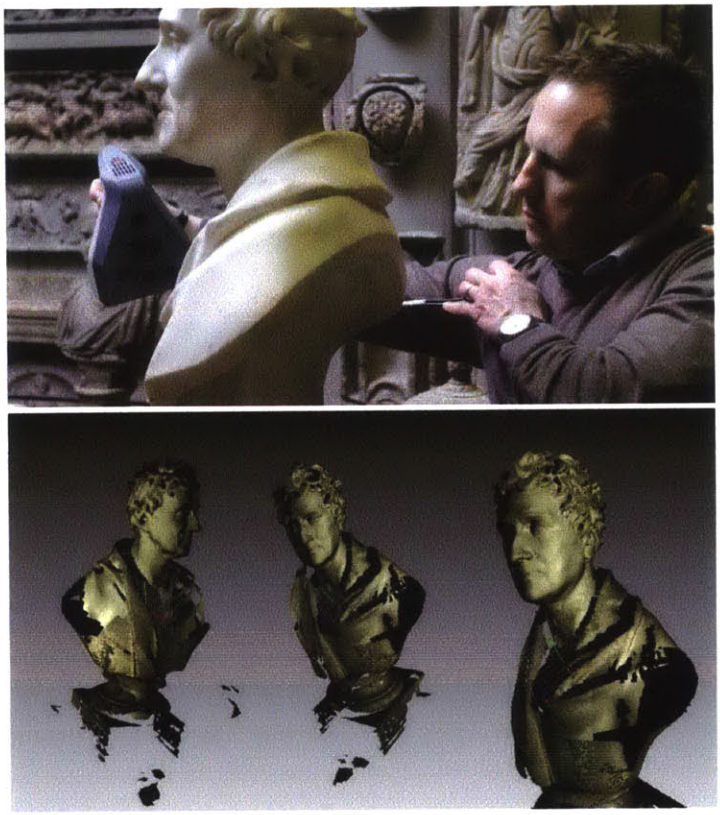


I-2. 3D PRINTING AND PRESERVATION

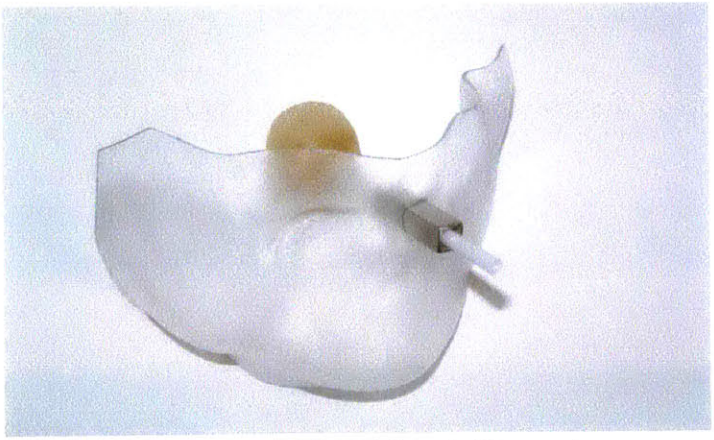
Re-Storing City

Re-Producing City

Left_3D Scanned Piazza del Duomo

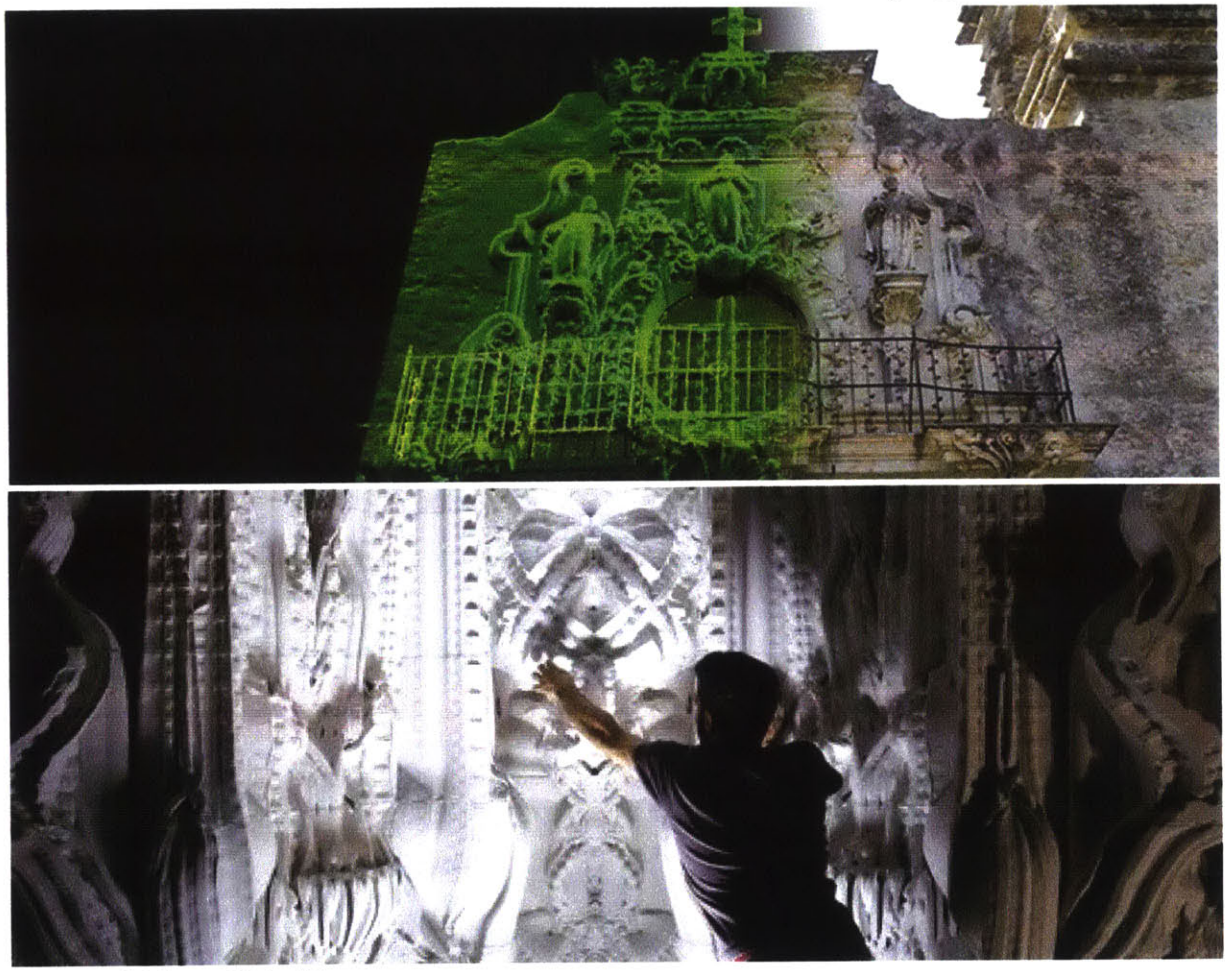


3D Scanning of the Bust of Sir John Soane



Reinterpreted Artwork from the 3D scanned

CyArk_3D Heritage Archive Network

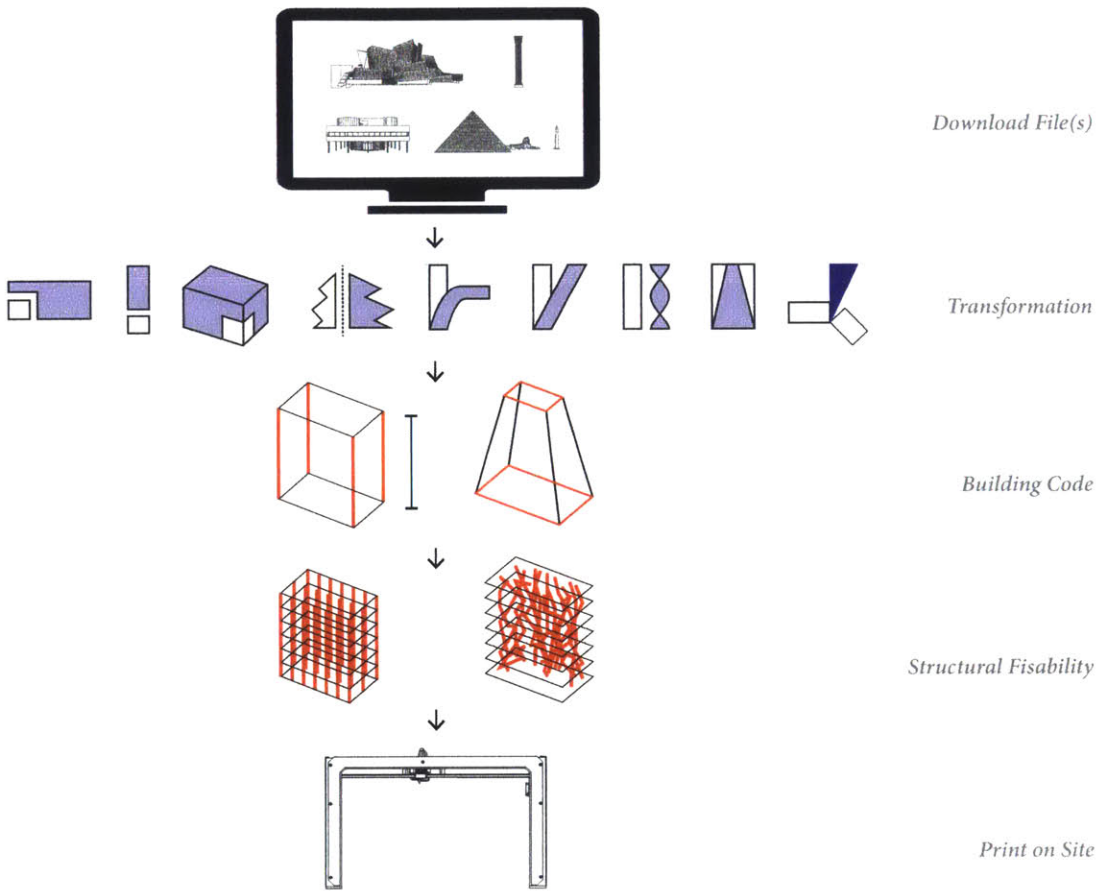


Ornamented Columns_Michael Hansmeyer

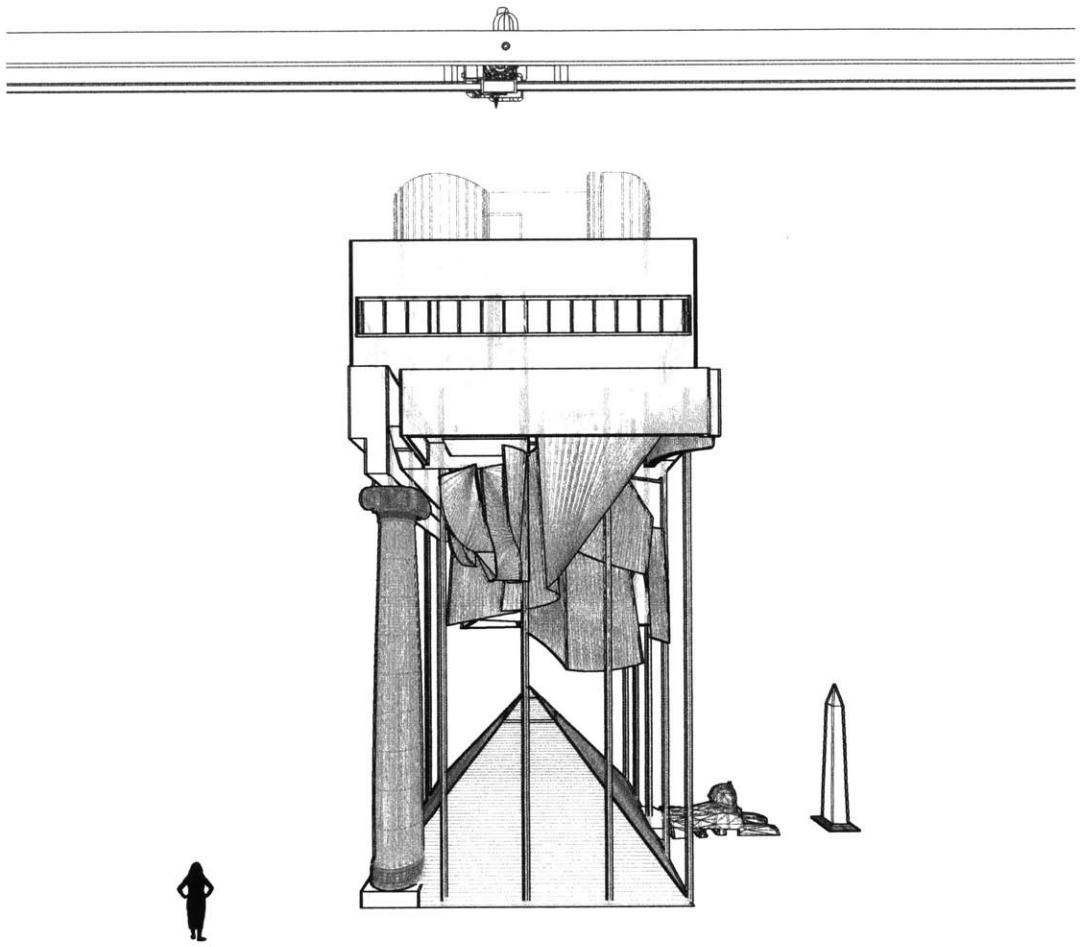
RE-STORING CITY

by 3D Scanning & 3D Printing

The Royal College of Art has recently tasked 3D scanning specialists with scanning a bust of Sir John Soane, one of Regency London's most prominent architects and indefatigable collector of archaeological artefacts, founder of Sir John Soane's Museum in central London. Once scanned, the 3D bust was digitally shattered and its digital fragments, 3D printed in various materials, were given to a host of RCA Jewellery & Metal graduates to be used as starting points for new contemporary art objects. That was how the Digital Soane competition started, and it was aimed at marrying the processes of hands-on craftsmanship with the latest digital technologies, 3D scanning and printing.



REPRODUCTING PROCESS



RE-PRODUCING CITY

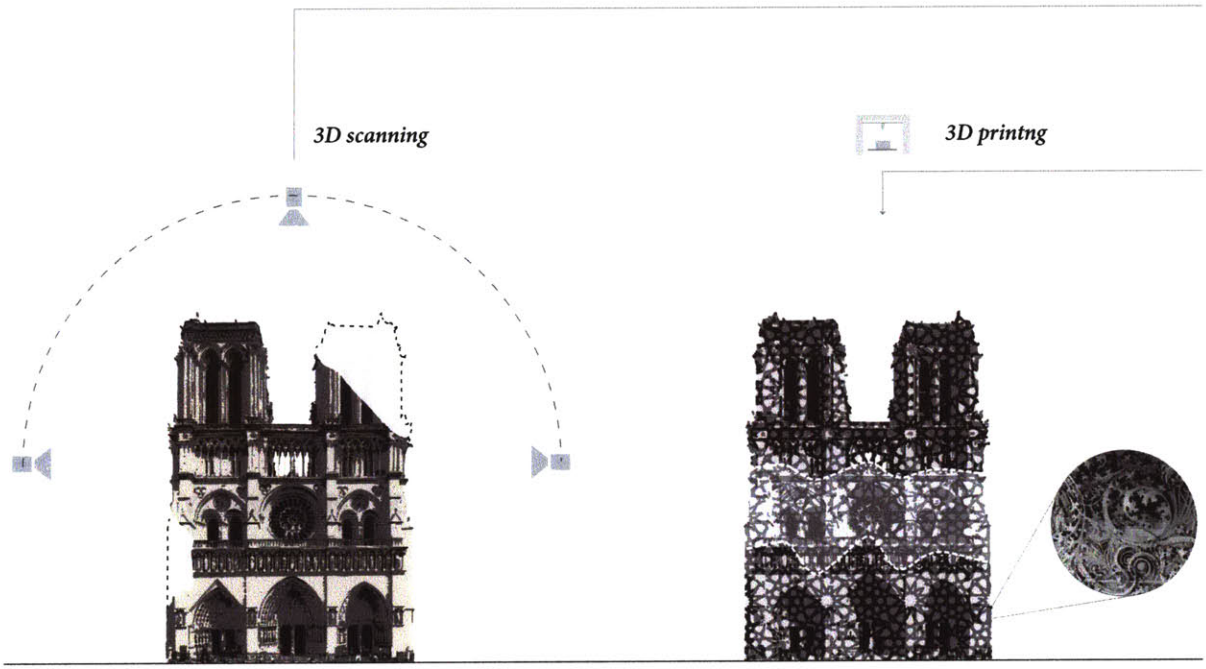
From a small toy to a magnificent building, 3D printing will be used to produce in a much cheaper and efficient way. Although many products will be still "Created " as new and unique entities, more and more things will be "Reproduced" based on an original file, in order to save time and money.

As a printing process, people will first buy copyright of a product and then will decide whether to print as it is or to transform it before they print it. And this might change how a city is structured and looks like.

I-3. PANORAMA OF A FUTURE CITY

TRANSFORMATION SPECTRUM IN A CITY

According to the research, it can be speculated that a city will consist of four areas;
where Restoration, Componential Ornamentation, Typological Blend, and Atypical Morphing happens.

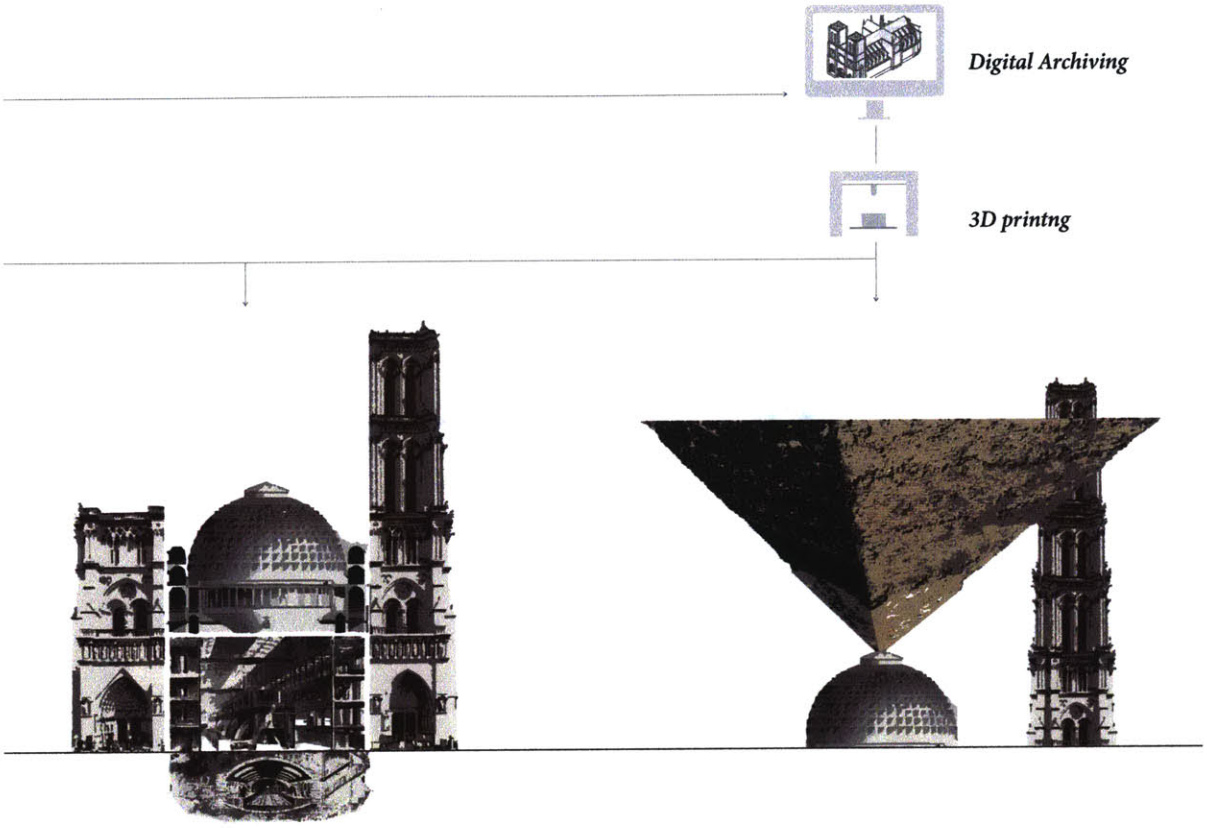


Restoration

In the Restoration area, built environments are digitally archived aided by 3D scanning technology and physically restored once any damages occur to them by traditional building technology. This area can be where heritages are placed and protected.

Ornamentation & Interior

In the Ornamentation area, built environments are embellished with 3D printed components, while maintaining traditional building technology and material. This area can be nearby heritage site.



Typological Blend

In the Typological blend area, multiple building typologies and functions are merged, maintaining their own typological features. This as a complex constitutes a manufacturing hub. Traditional building materials are used to construct this area.

Atypical Morphing

In the Atypical morphing area, different typologies and functions are merged, ruining their own typological features. Digitally archived objects are morphed and booleaned. Traditional materials are used but authentic building technologies are replaced by 3DP technology.

II. SITE RESEARCH

II-1. SITE SELECTION

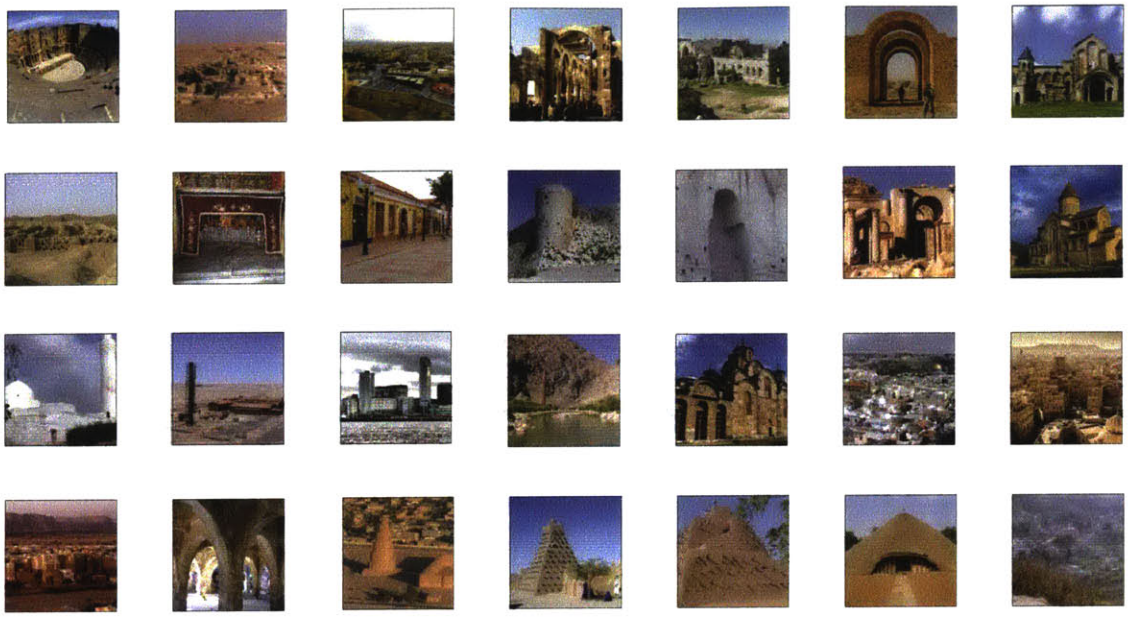
Criteria of Site Selection

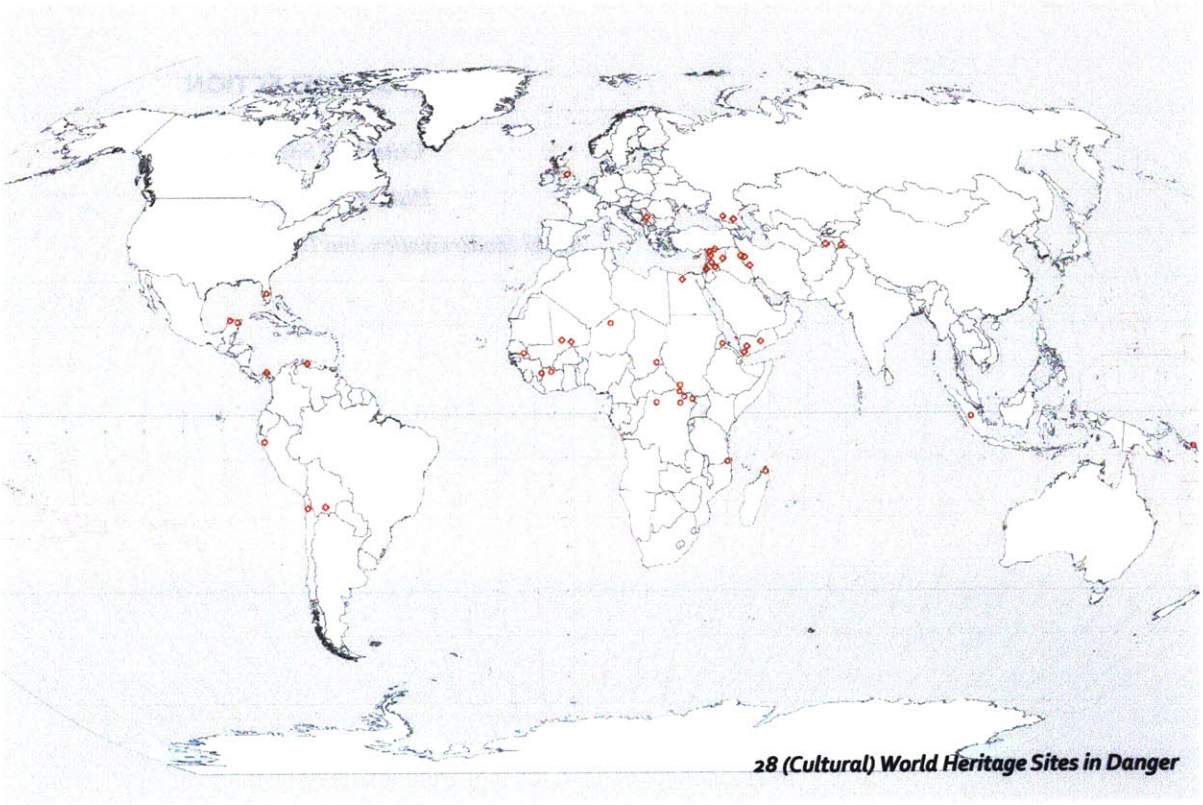
History of Sana'a, Yemen

Rapid Modernization and Degeneration

Left_3D Scanned Piazza del Duomo

World Heritage Site in Danger



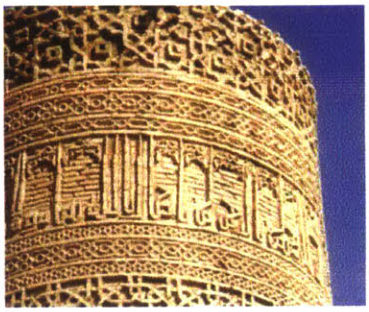


28 (Cultural) World Heritage Sites in Danger

Tradition of Craftsmanship & Ornamentation

Jewerly

Soil

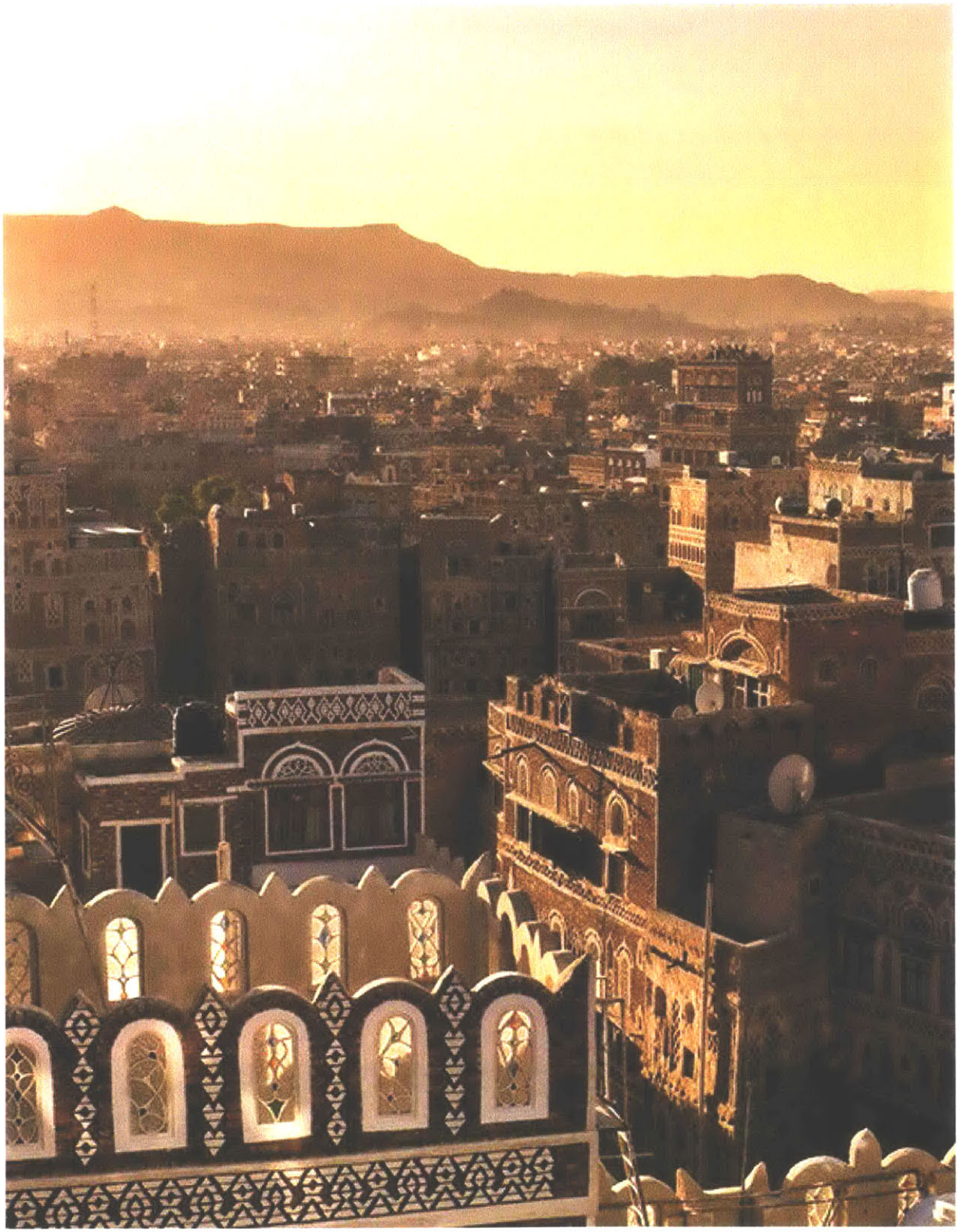


Plaster

Rapid Modernization

CRITERIA OF SITE SELECTION

In choosing a project site, three specific criteria were considered;
World heritage site in danger, Long tradition of craftsmanship and ornament, and Rapid modernization. Those criteria were considered in order to find a place where has abundant heritages need to be restored and preserved. And at the same time a place where has a huge potential of transformation of those original.



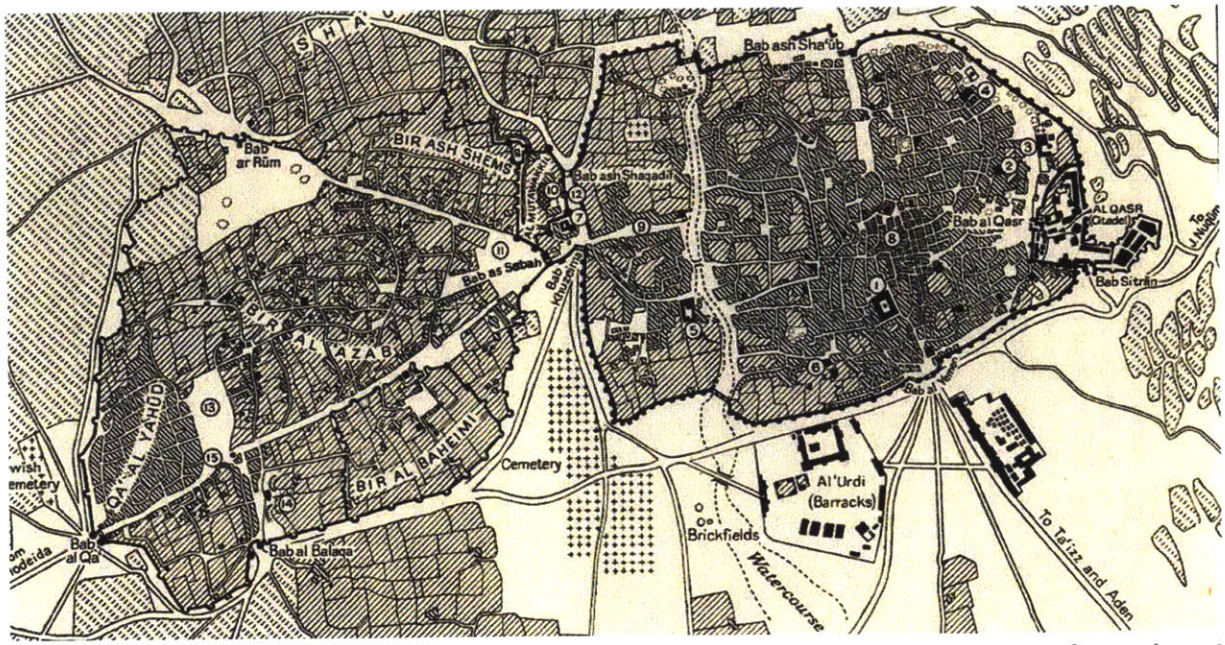
Old City Sana'a

HISTORY OF SANA'A, YEMEN

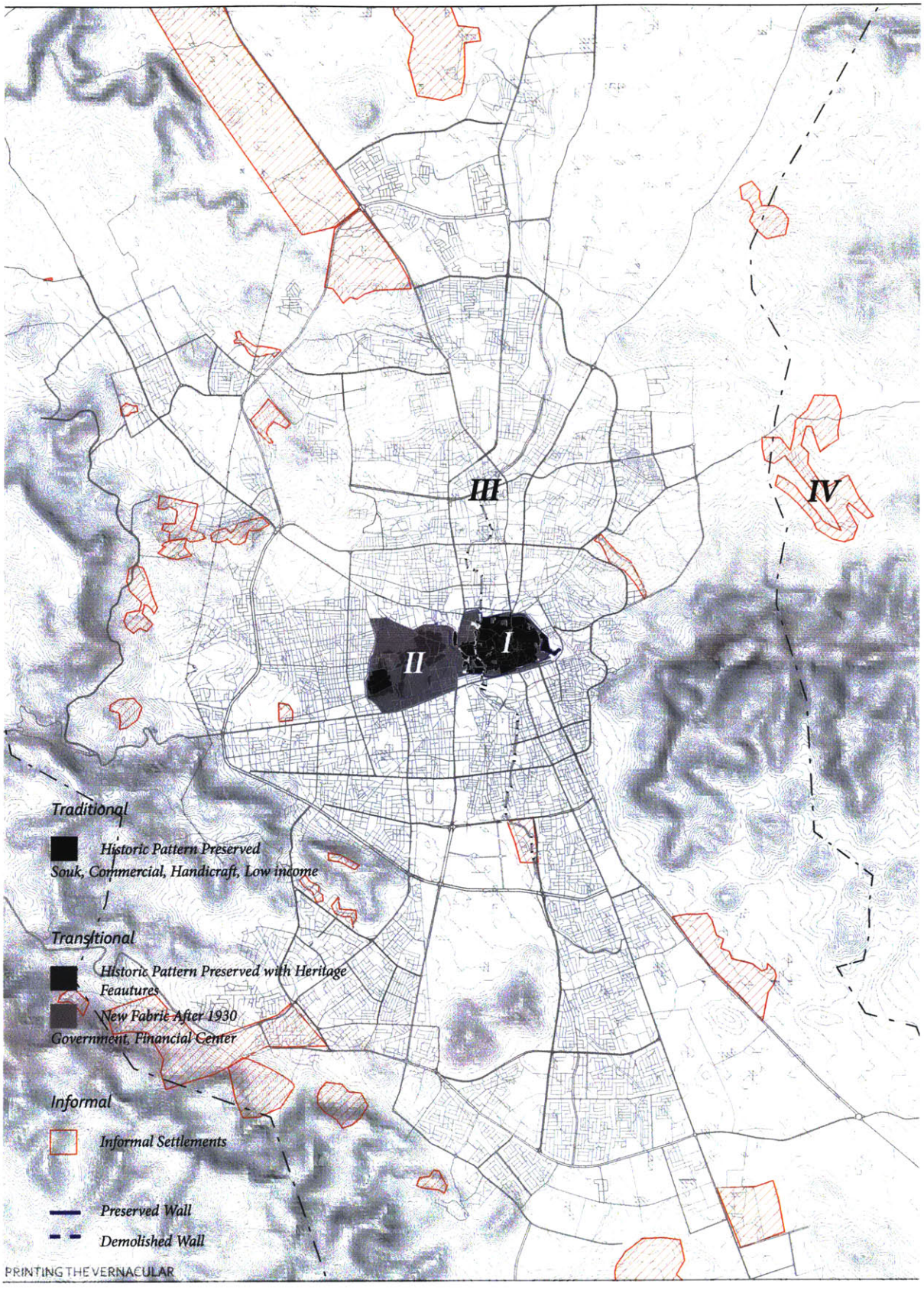
Sana'a is the largest city in Yemen and the centre of Sana'a Governorate. Sana'a is one of the oldest continuously inhabited cities in the world. At an altitude of 2,300 metres (7,500 ft), it is also one of the highest capital cities in the world. Sana'a has a population of approximately 1,937,500 (2012), making it Yemen's largest city.

The old city of Sana'a, a UNESCO World Heritage Site, has a distinctive visual character due to its unique architectural characteristics, most notably expressed in its multi-storey buildings decorated with geometric patterns. In the conflict that raged in 2015, bombs hit UNESCO sites. Located here is the Great Mosque of Sana'a, the largest in the city.

Location of Sana'a in Yemen



Map of Sana'a in 1946


III
IV
II
I
Traditional
Historic Pattern Preserved
Souk, Commercial, Handicraft, Low income
Transitional
Historic Pattern Preserved with Heritage Feautures
New Fabric After 1930
Government, Financial Center
Informal
Informal Settlements
Preserved Wall
Demolished Wall

Sana'a in 2015

RAPID MODERNIZATION AND DEGENERATION

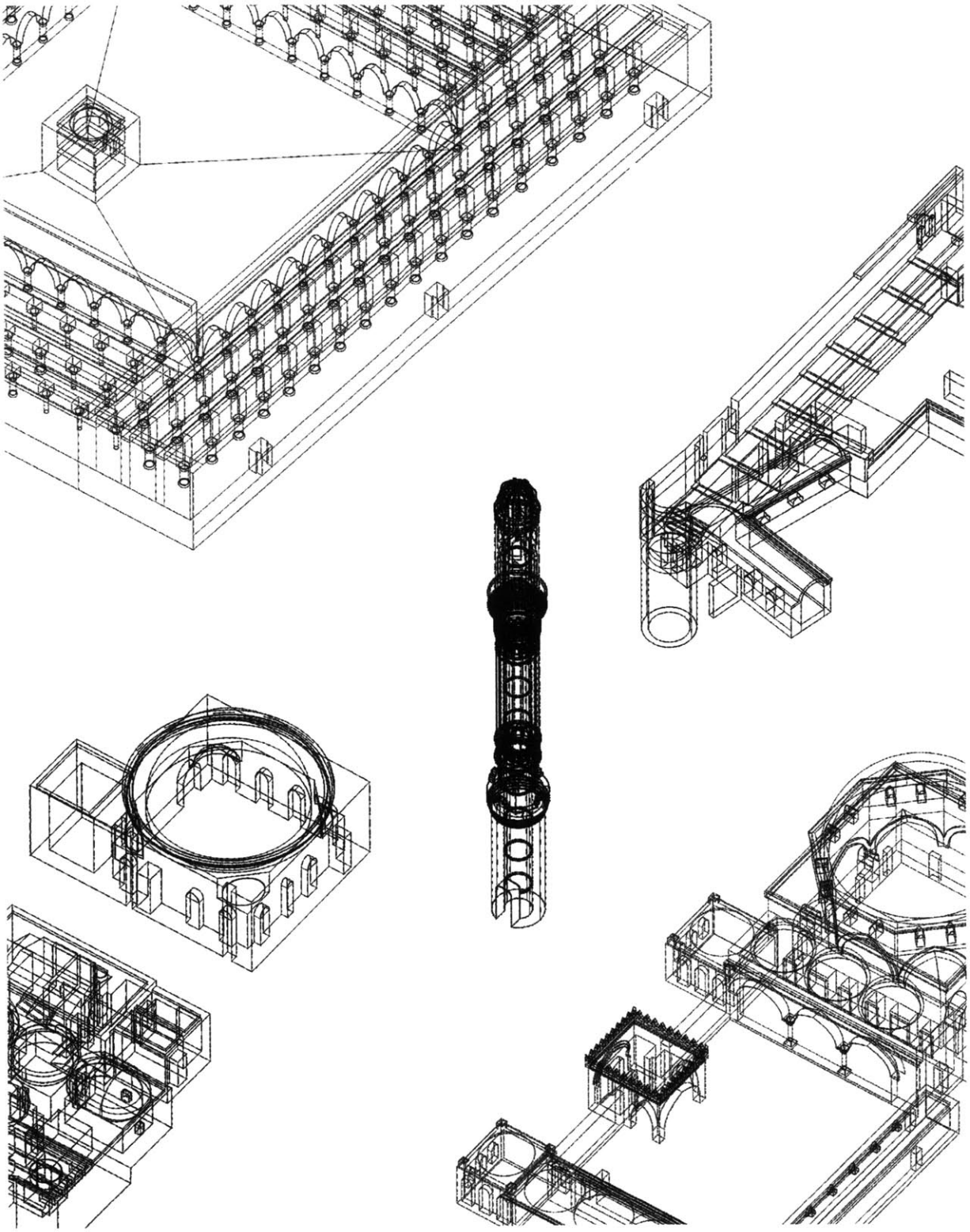
The survey carried out shows that very intense building activity has occurred in the perimeter in the last 15 years. In the residential quarters, 4145 buildings appear to have undergone interventions of different types. Amongst these interventions, the construction of "new buildings" count for 31% of the total and are mainly concentrated in the new developments along the city walls, on the northern and south-western sides, even if many isolated interventions can be found within the historic fabric. Adding to this the "reconstruction" and "redevelopment" of pre-existing buildings, it appears that 42% of interventions have implied the construction of new structures; in other terms, that about 18% of the buildings inventoried in the perimeter are recent. On the other hand, the amount of interventions of renovation, rehabilitation and restoration show a high degree of maintenance and reuse, which may be considered as an outcome of the protection measures established and the control on building activities enforced by the GOPHCY since the 1990s, which have probably prevented a larger amount of reconstruction and redevelopment interventions.

restoration

addition

rehabilitation/reconstruction

new construction



II-2. BUILDING TYPOLOGIES OF SANA'A

Building Typology

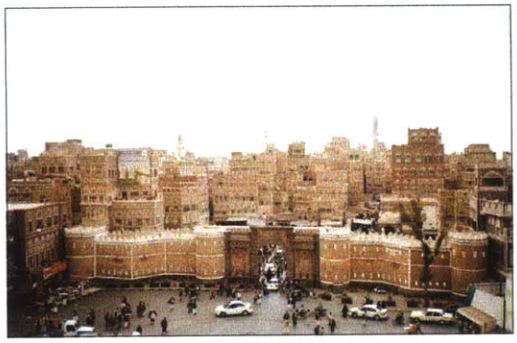
Features of Tower House

Signification of Ornament

Left_Catalogue of Different Building Typologies in Sana'a

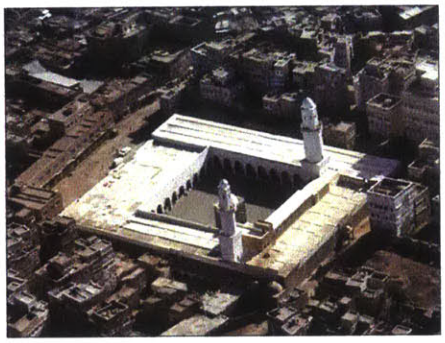
BUILDING TYPOLOGY

The old city of Sana'a, a UNESCO World Heritage Site, has a distinctive visual character due to its unique architectural characteristics, most notably expressed in its multi-storey buildings decorated with geometric patterns. Among them, there are six major building typologies; Wall, Mosque, Minaret, Hammam, Caravanserai, and Tower House.



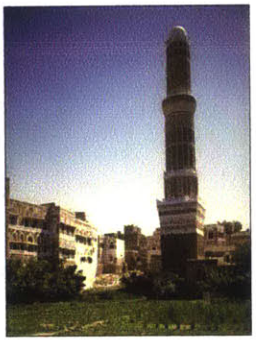
the Wall

the city walls have been reconstructed with the intention of recreating the historical and traditional image but in fact, in a certain places, their shape, thickness and line have been seriously altered.



Mosque

Mosque is the spiritual space that connects human with Allah; here the human soul rises with faith. Mosque plays various roles in the society such as a place of worship, learing the Quran, and as soome cases, the serious issues are settled in the mosque either of an individual or as community.



Minaret

In addition to providing a visual cue to a Muslim community, the main function of the minaret is to provide a vantage point from which the call to prayer, or adhan, is made.

Hamman(bath)

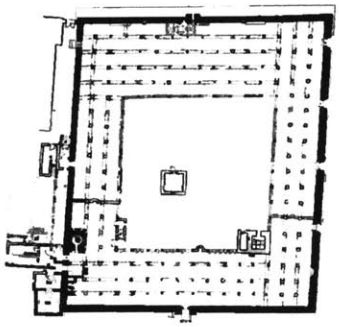
Establishemnt of a hot bath in public places fulfils the Islamic requirements for cleanliness and the high cost of heating in individual houses during winters. It usually built next to the mosque to share water and easy access for both male and female inhabitants of a quarter

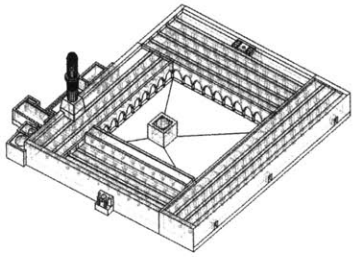
Caravanserai

A caravanserai was a roadside inn where travelers could rest and recover from the day's journey. In the Middle-East, it is often called by its Persian name khan.

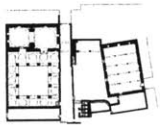
Tower house

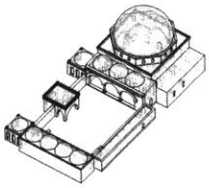
Tower house is a vertical housing that has five floors and above. A number of tower houses forms the housing unit within a qurter. Each tower houses varies in the space and layout and the number of floors reflect the owner's occupation hierarchy in the society





— Great Mosque





Mosque of al-Bakiriyyah



Addil Minaret

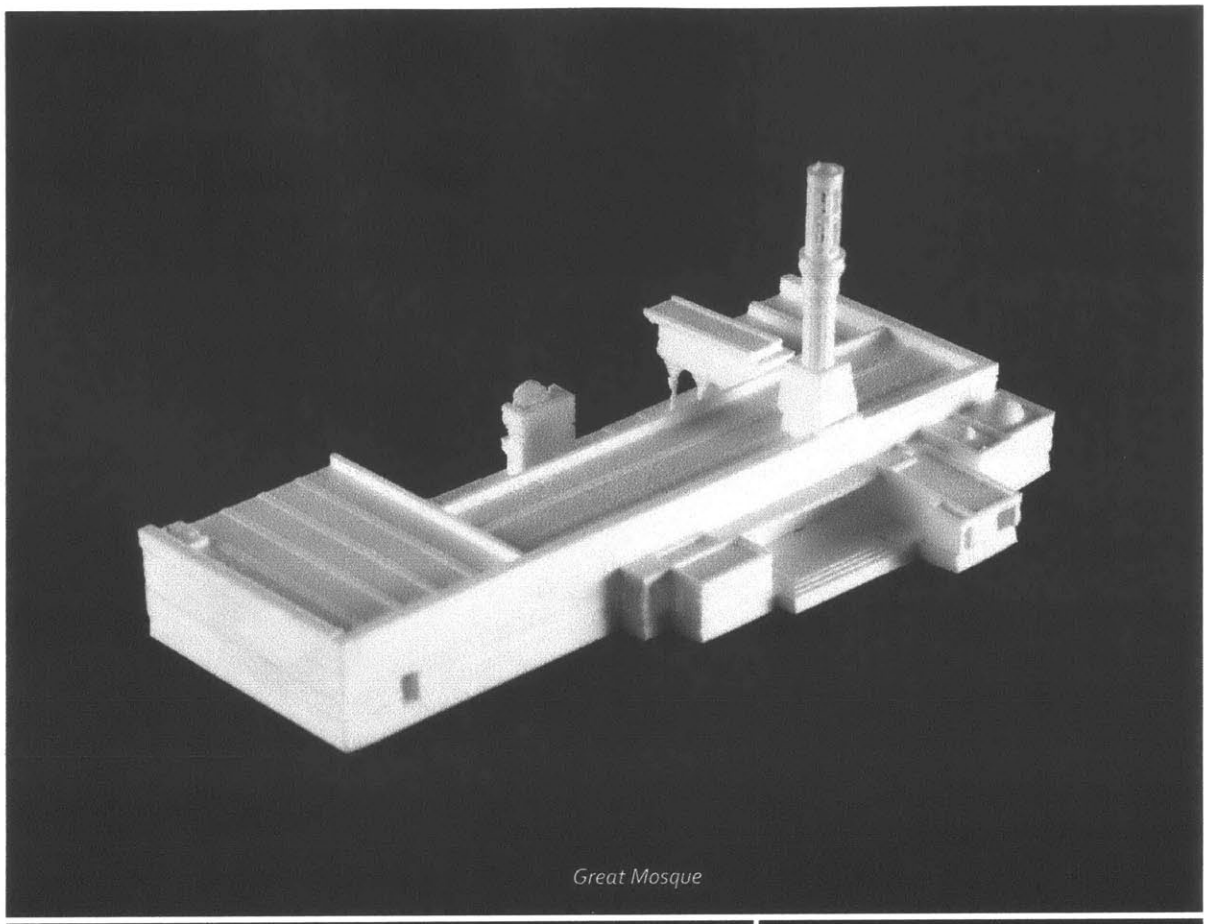


Hammam Shukr

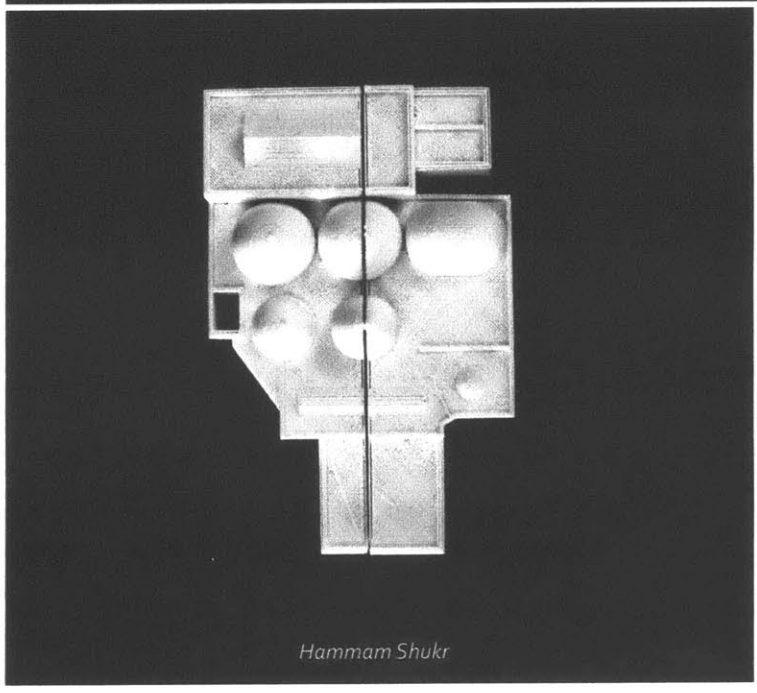


Samsarat Mansurah

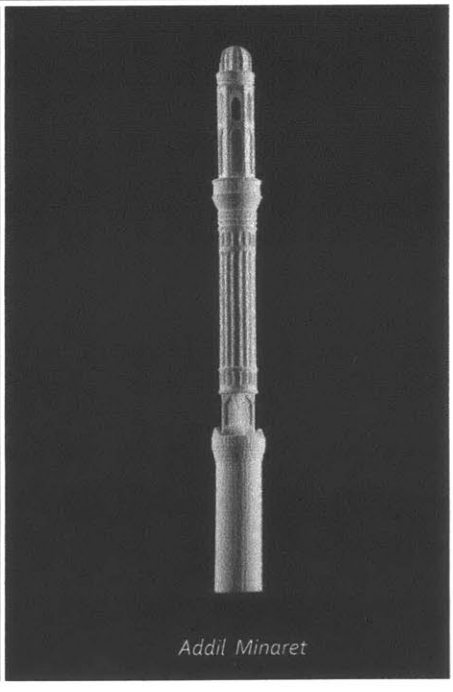

Tower House JY



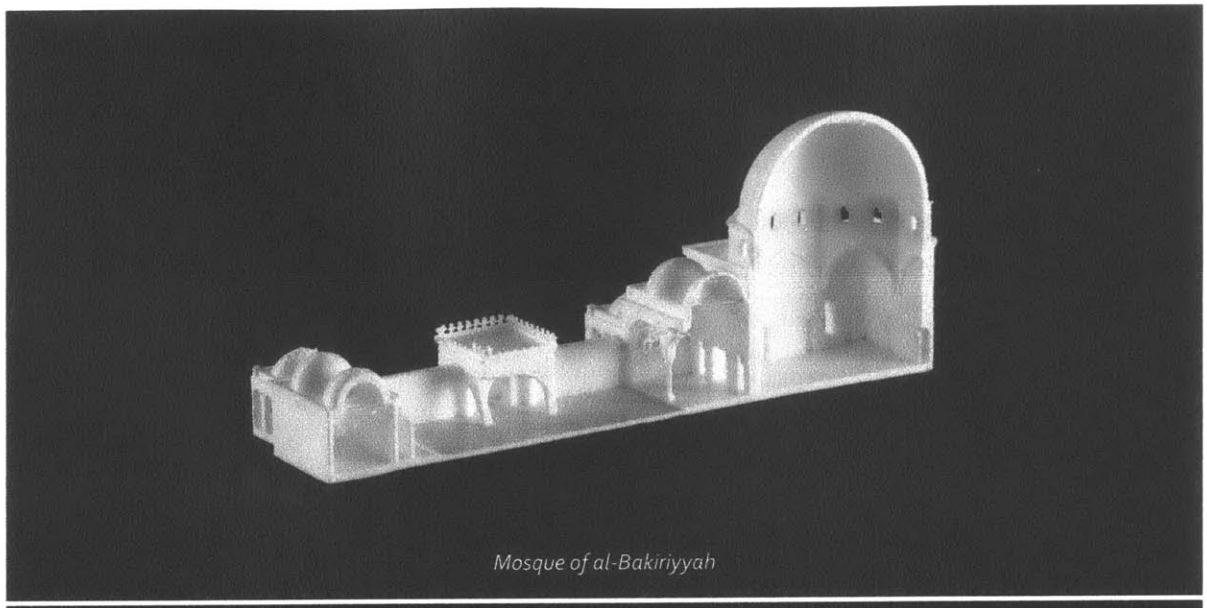
Great Mosque



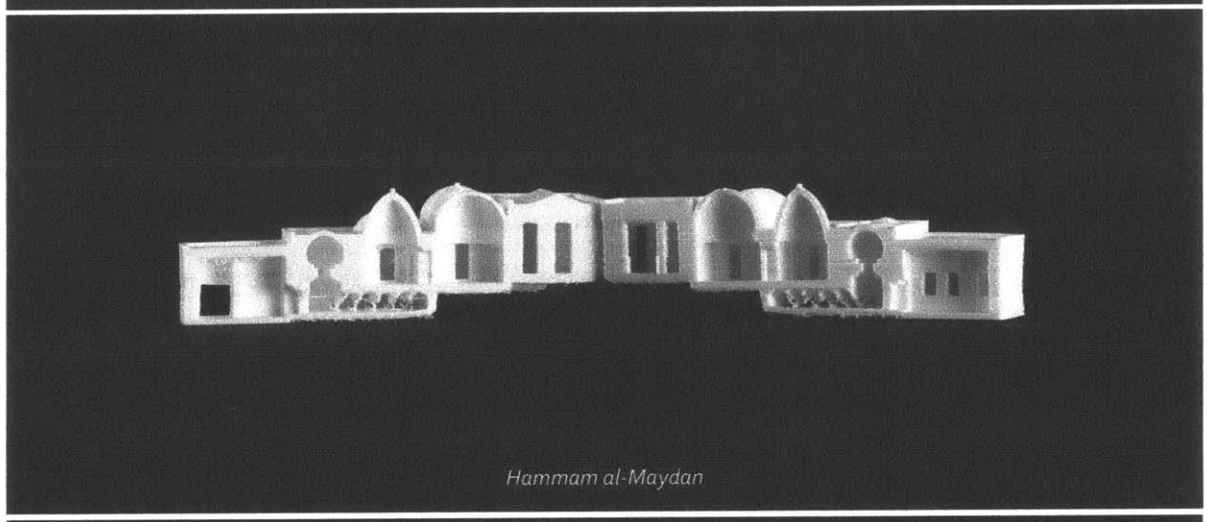
Hammam Shukr



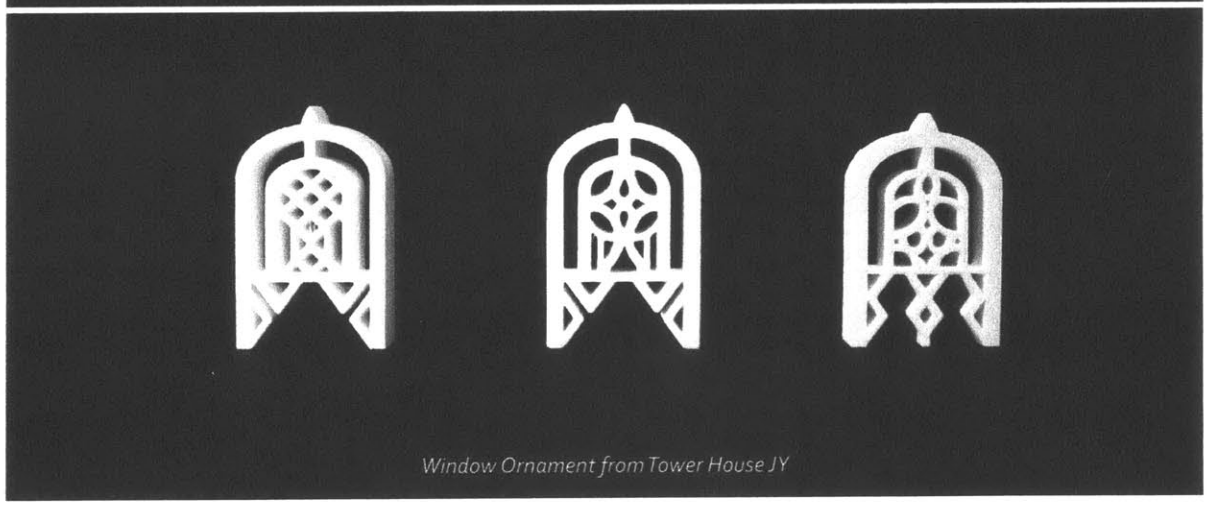
Addil Minaret



Mosque of al-Bakiriyyah

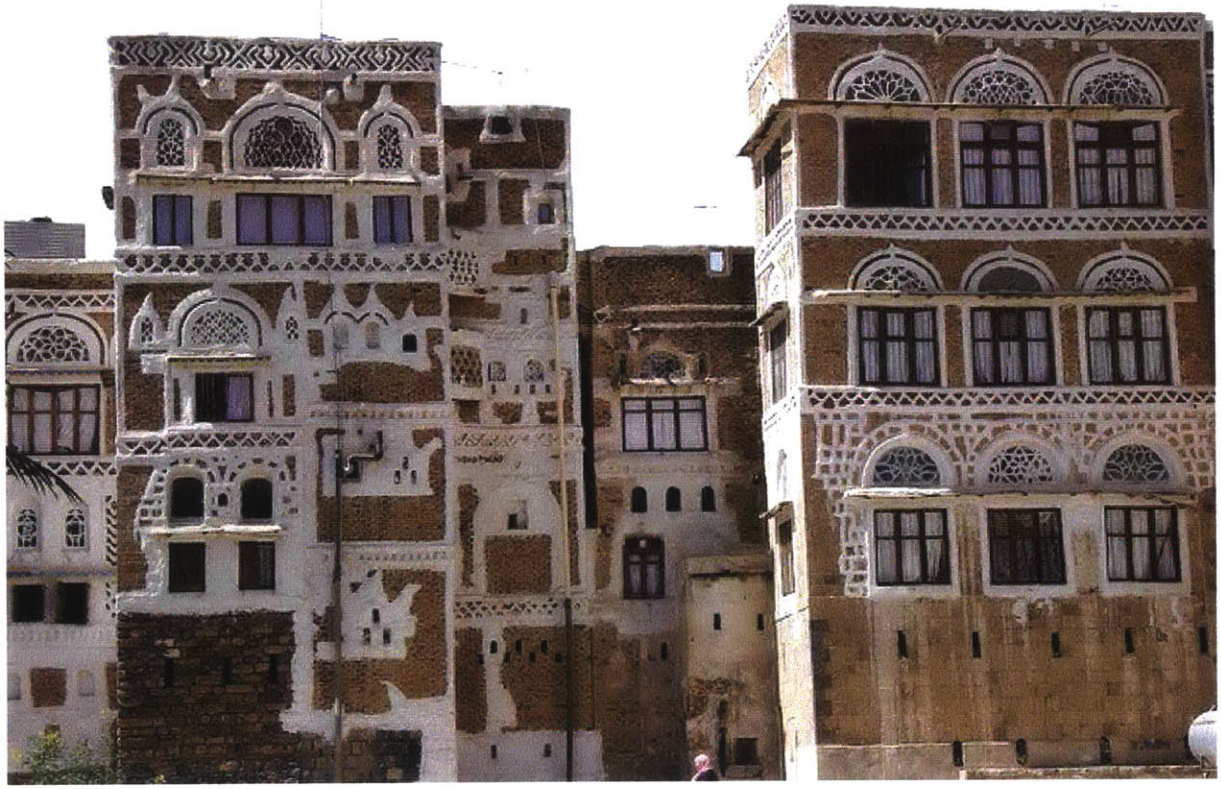


Hammam al-Maydan

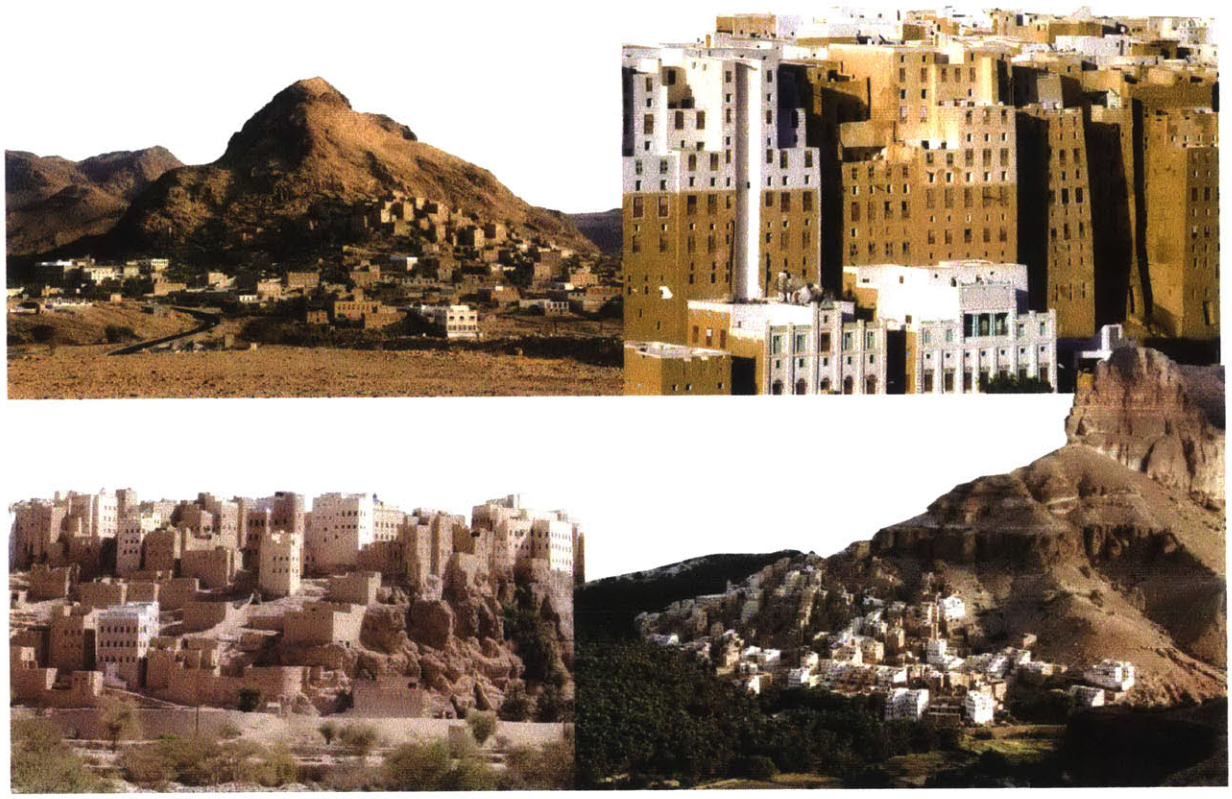


Window Ornament from Tower House JY

3D PRINTED BUILDING TYPOLOGIES FROM DIGITAL ARCHIVE



Typical Tower Houses in the Old City Sana'a



Variations of Tower Houses near Sana'a

FEATURES OF TOWER HOUSE

The predominantly square tower houses impress the visitor with their height. Many houses are more than five storeys high, the largest commonly having seven, eight or even nine storeys. A view of the city from a distance, with many hundreds of these houses soaring above the city walls, makes an unforgettable impression. The streets of the towns are generally narrow and flanked by towering houses with no sight of vegetation or water to relieve the eye, yet behind the houses and extending right up to them there are frequently large gardens. These are the waqf foundations which support the mosques; they are planted with vegetables and fruit which are sold to the inhabitants of the encircling houses, the surplus going to the market. Thus almost every house, even in Sana'a has a view through its windows into extensive gardens. The cultivated areas frequently appear sunken, and indeed it was from these areas that earth was taken for the construction of the surrounding houses, but the effect is increased by the accretion of centuries of rebuilding along the streets, so that the building and street levels have risen several metres above the original ground level.

ORNAMENT

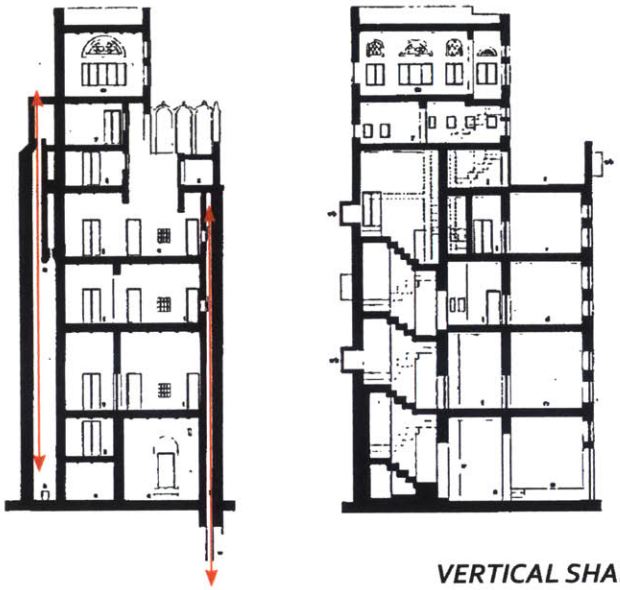
Tower houses in Sana'a, in most cases, have highly decorated window frames. Ornamentation of window frame is regarded advanced craftsmanship in Yemen

3 layouts

2 layouts

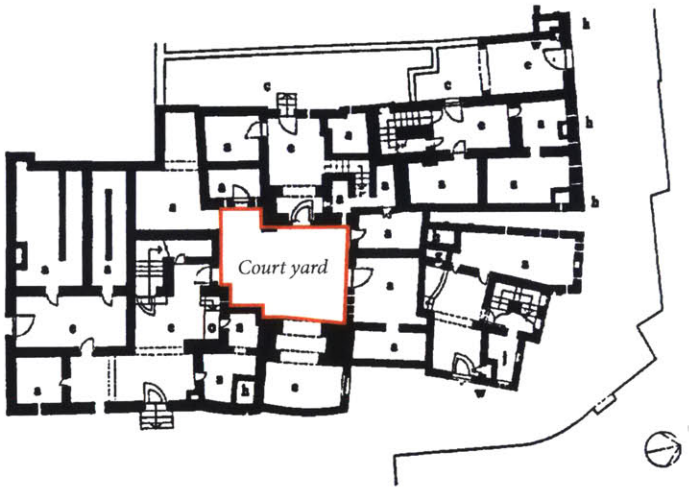
ADDITION OVER TIME

in many cases, tower houses have more than two layouts that were built over time



VERTICAL SHAFT

in most of tower houses, they have vertical shaft to deal with ventilation, water, human execretion, and etc.
also, size of rooms differentiated vertically according to programs



COMPLEX

in many cases, several tower houses are attached together, sharing a court yard in the middle

ORNAMENT AS ICONOGRAPHY

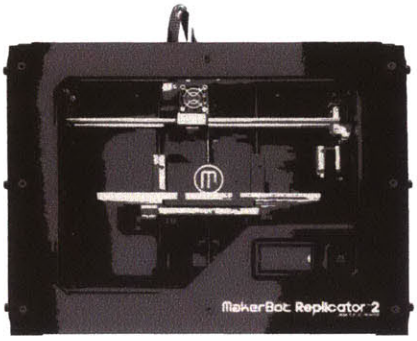
Stele with lamp motif, Badairiyya Madrasa, Cairo, Egypt, ca. 1350. Marble, 60 × 36 cm

ICONOGRAPHY OF LIGHT

Light is the most fundamental and ubiquitous metaphor in Islamic sculpture.
The key verse to understanding the role of light in Islam is Sura 24, verse 35 of the Qur'an, the Sura of Light, which states; 'God is the Light of the heavens and the earth; the likeness of His Light is as a niche wherein is a lamp.
Occasionally the mosque lamp appears as a decorative motif on stucco and window grilles, such as those from the early fourteenth century mausolea of Salar and Sanjar al-Jawli, where the actual passage of light through the lamp produces a further visual evocation of divine illumination.

Plaster Window Ornamentation

+



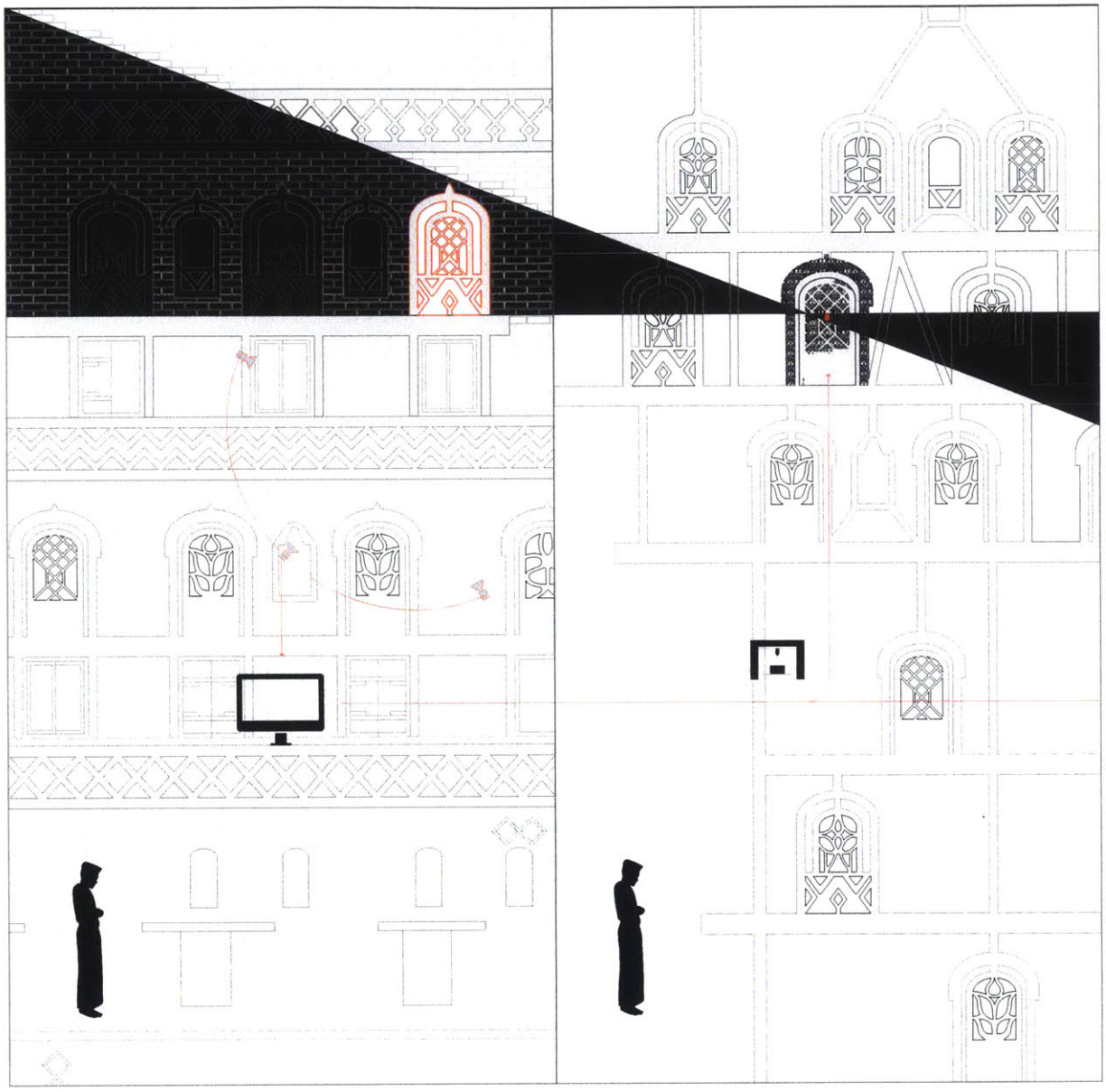
3D Printing Technology

This thesis is posing a question, "what if the city of Sana'a is adopting the new technology, 3D printing technology in the future?". And it is testifying possibility of transforming ornament which has a significant meaning for Yemeni people.

II-3. TRANSFORMATION OF ORNAMENT

Scaling Ornament

Panorama of Future Sana'a

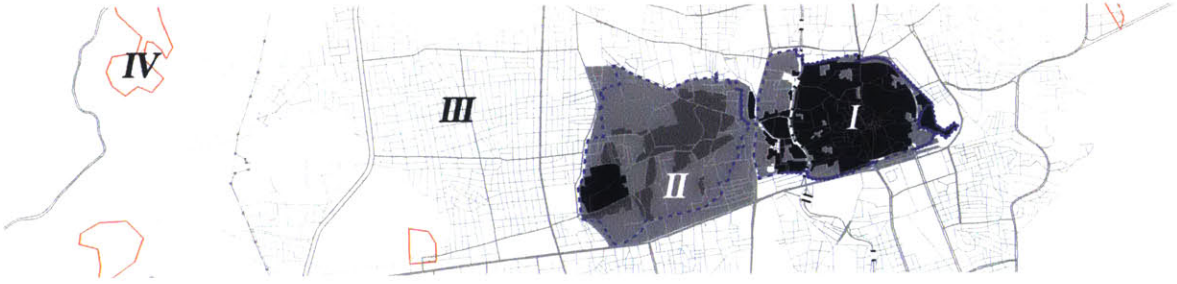


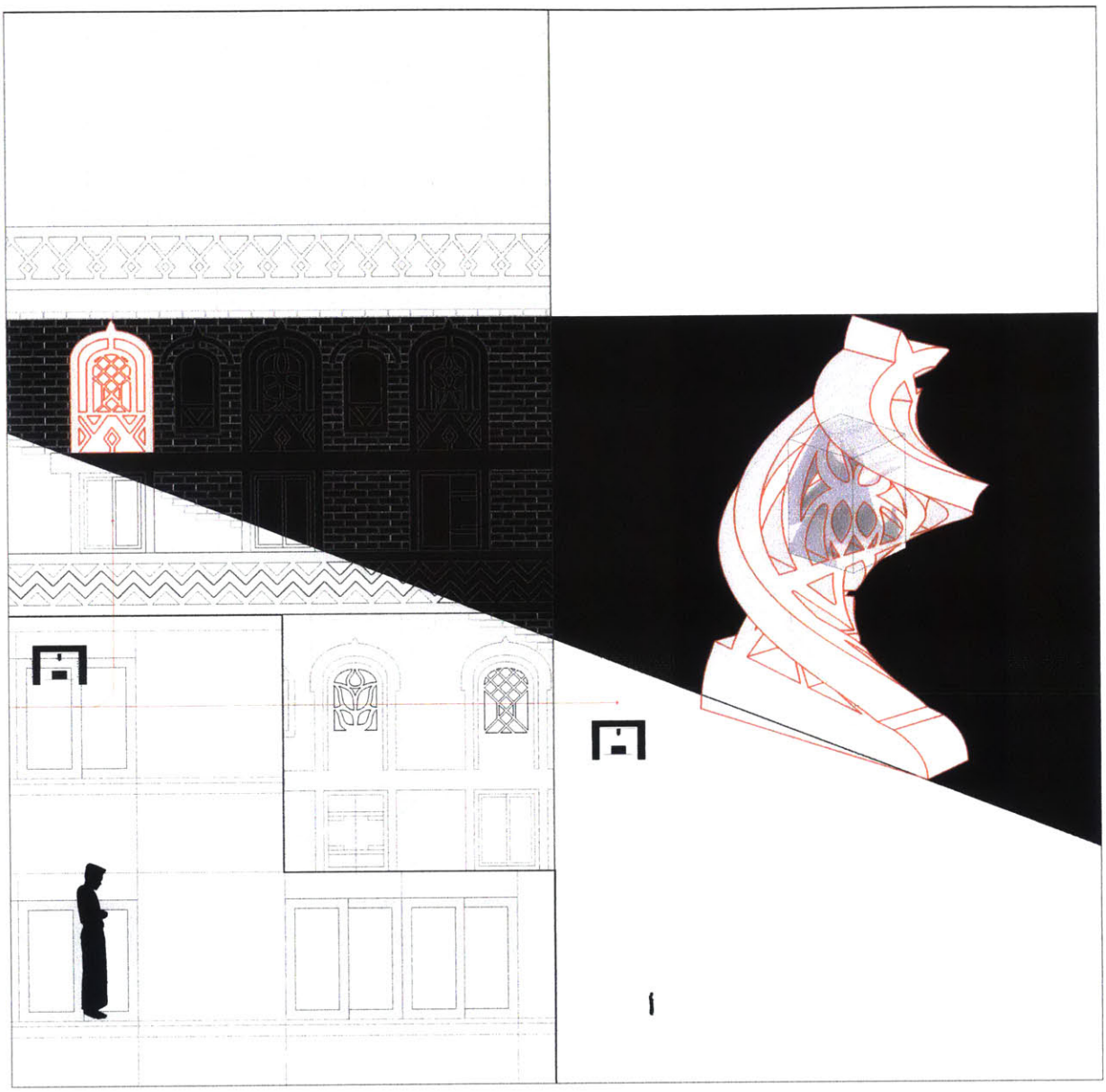
AREA I

Iconography

AREA II

Higher Resolution & Structure





AREA III
Juxtaposition

AREA IV
Inhabitable Ornament

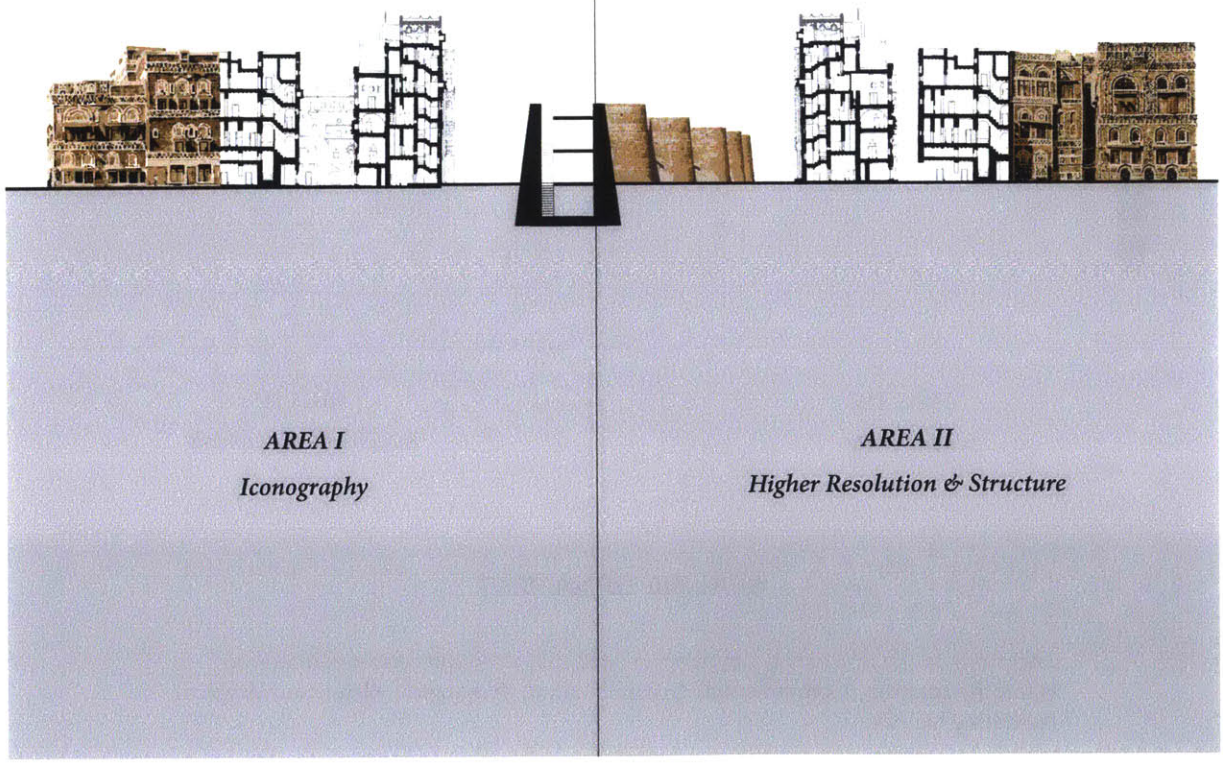
SCALING ORNAMENT

According to the research, it can be speculated that a city will consist of four areas; where Restoration, Componential Ornamentation, Typological Blend, and Atypical Morphing happens.

PANORAMA OF FUTURE SANA'A

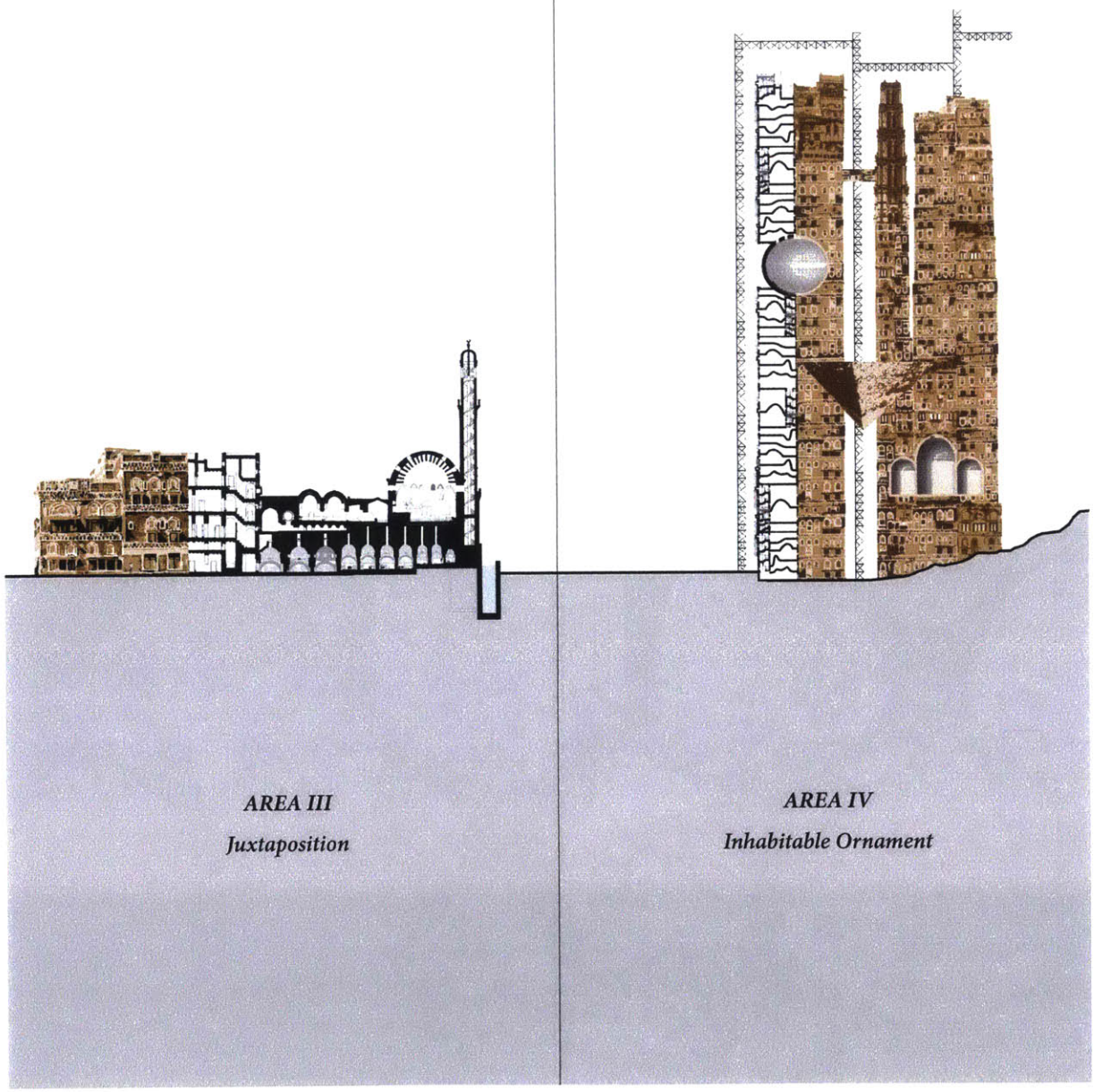
In the Iconography area, built environments are digitally archived aided by 3D scanning technology and physically restored once any damages occur to them by traditional building technology. This area can be where heritages are placed and protected.

In the Ornamentation area, built environments are embellished with 3D printed components, while maintaining traditional building technology and material. This area can be nearby heritage site.



In the Juxtaposition area, multiple building typologies and functions are merged, maintaining their own typological features. This as a complex constitutes a manufacturing hub. Traditional building materials are used to construct this area.

In the Inhabitable Ornament area, part of ornament scaled and morphed so that it becomes large enough to inhabit inside. Thus, people have intimate relationships with ornament, becoming part of it.

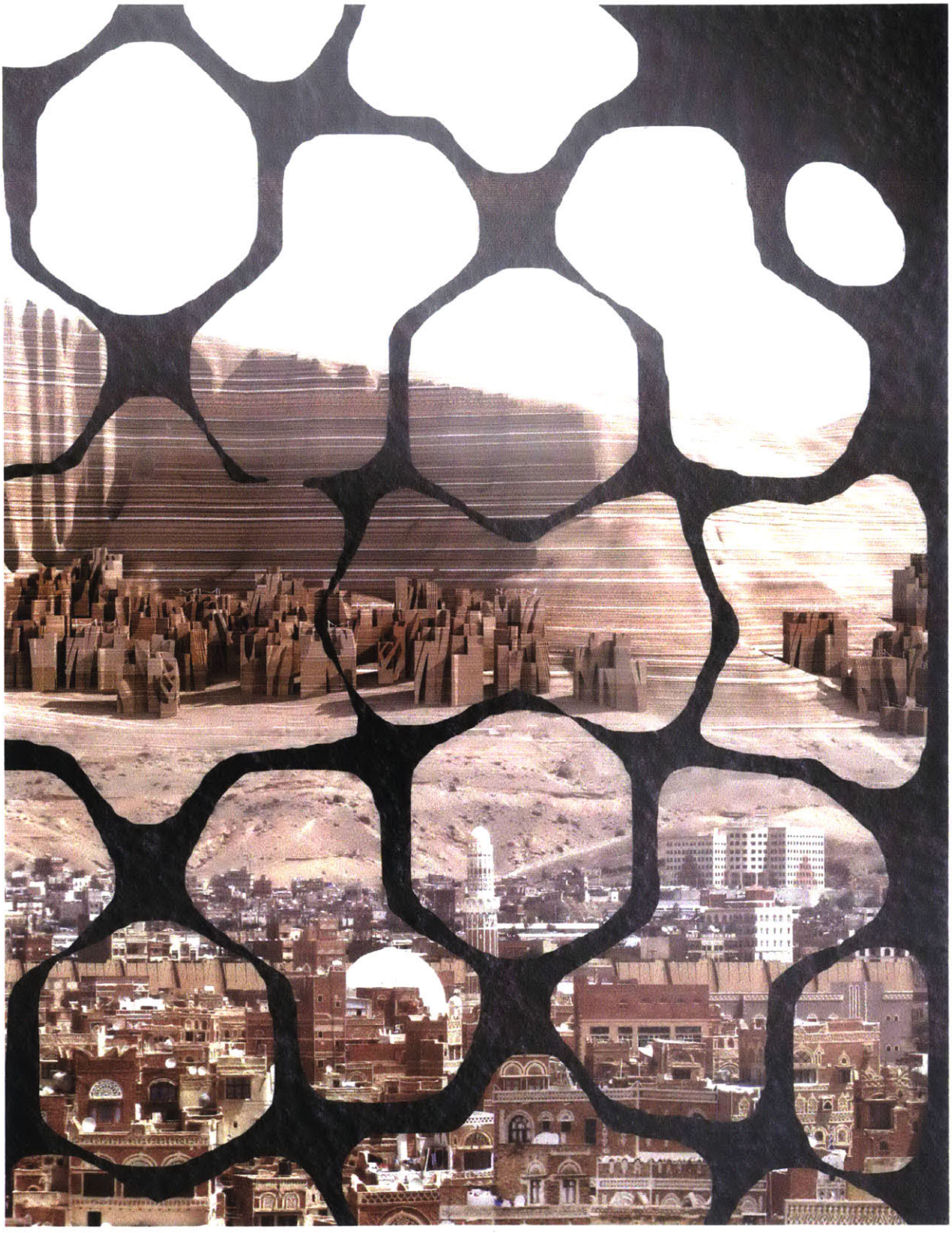


AREA III

Juxtaposition

AREA IV

Inhabitable Ornament

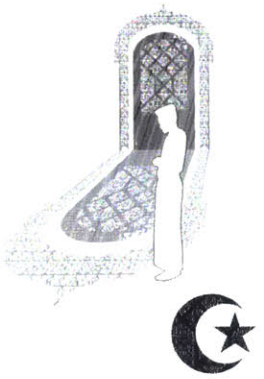


III. PROPOSAL

SPECULATION OF FUTURE SANA'A

Area II_Higher Resolution Ornament
Area III_Juxtaposition
Area IV_Inhabitable Ornament

Ornament as Iconography of God

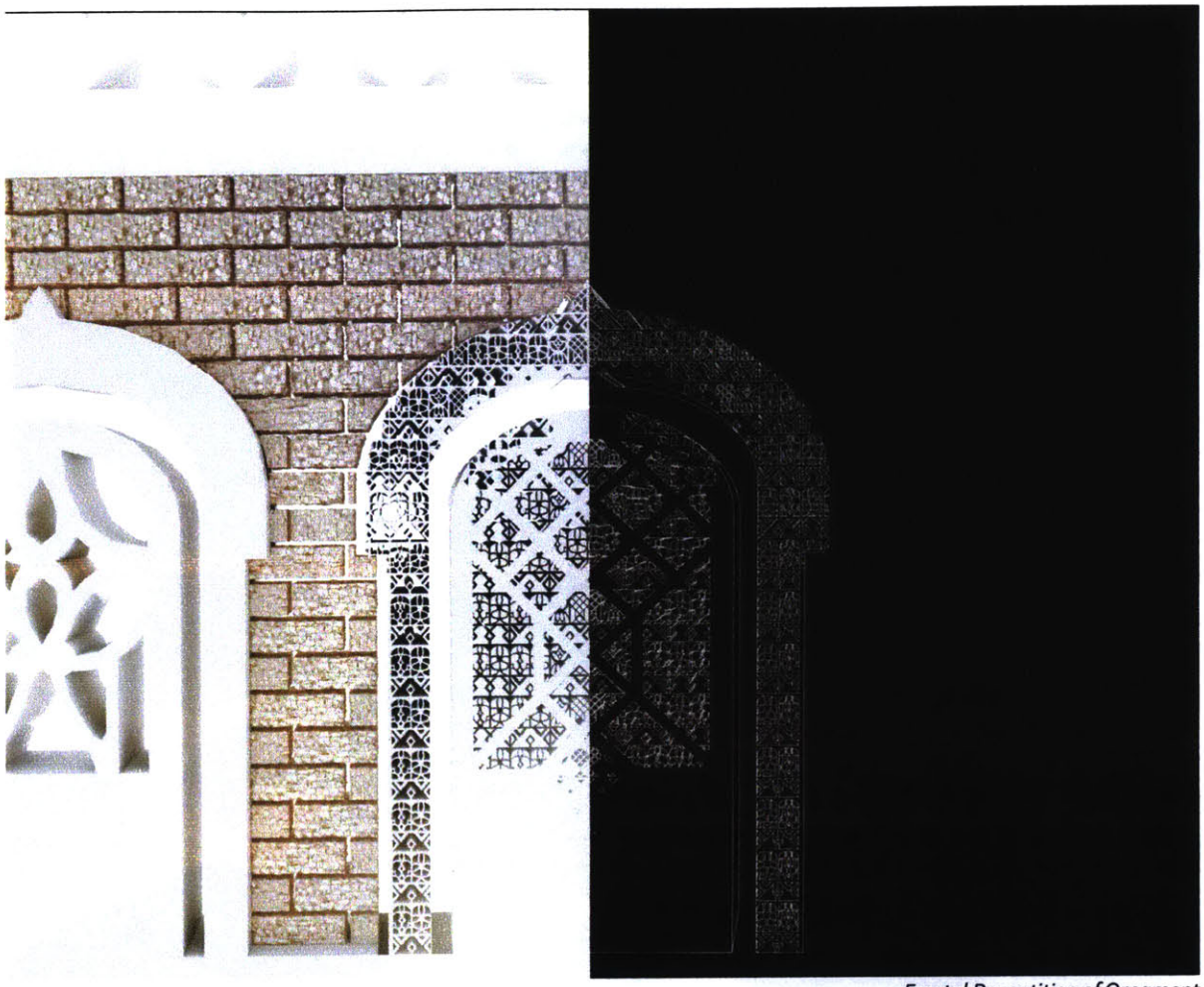


Higher Resolution of Ornament by 3D printer

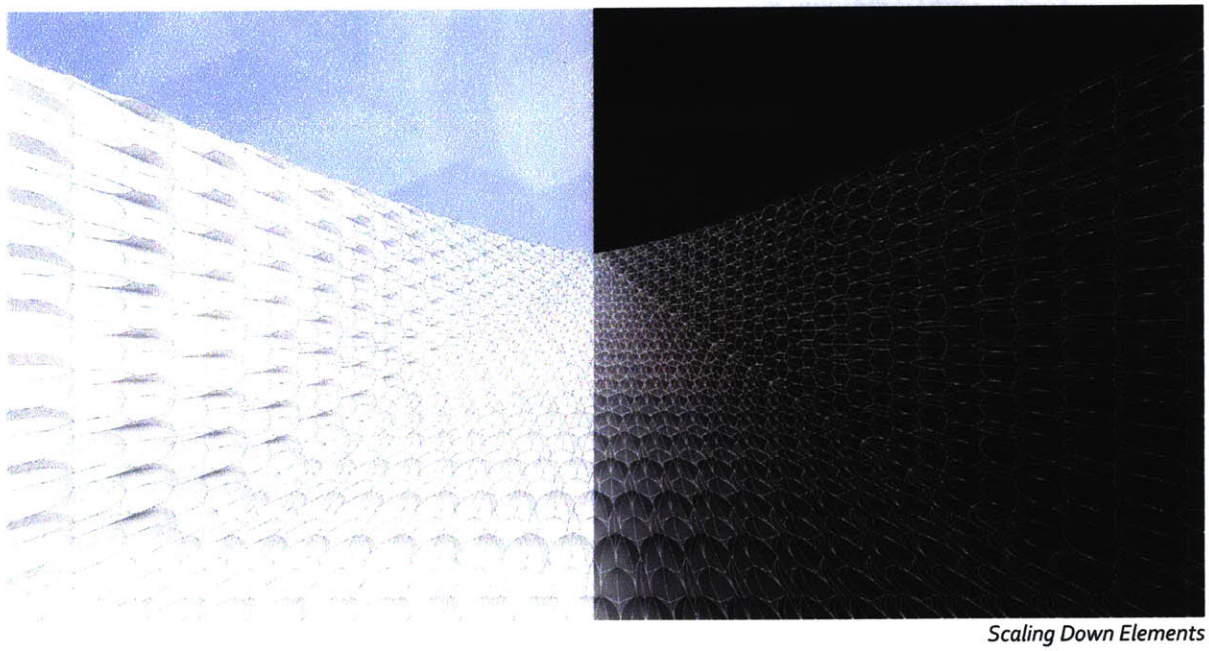
AREA II

Higher Resolution Ornament

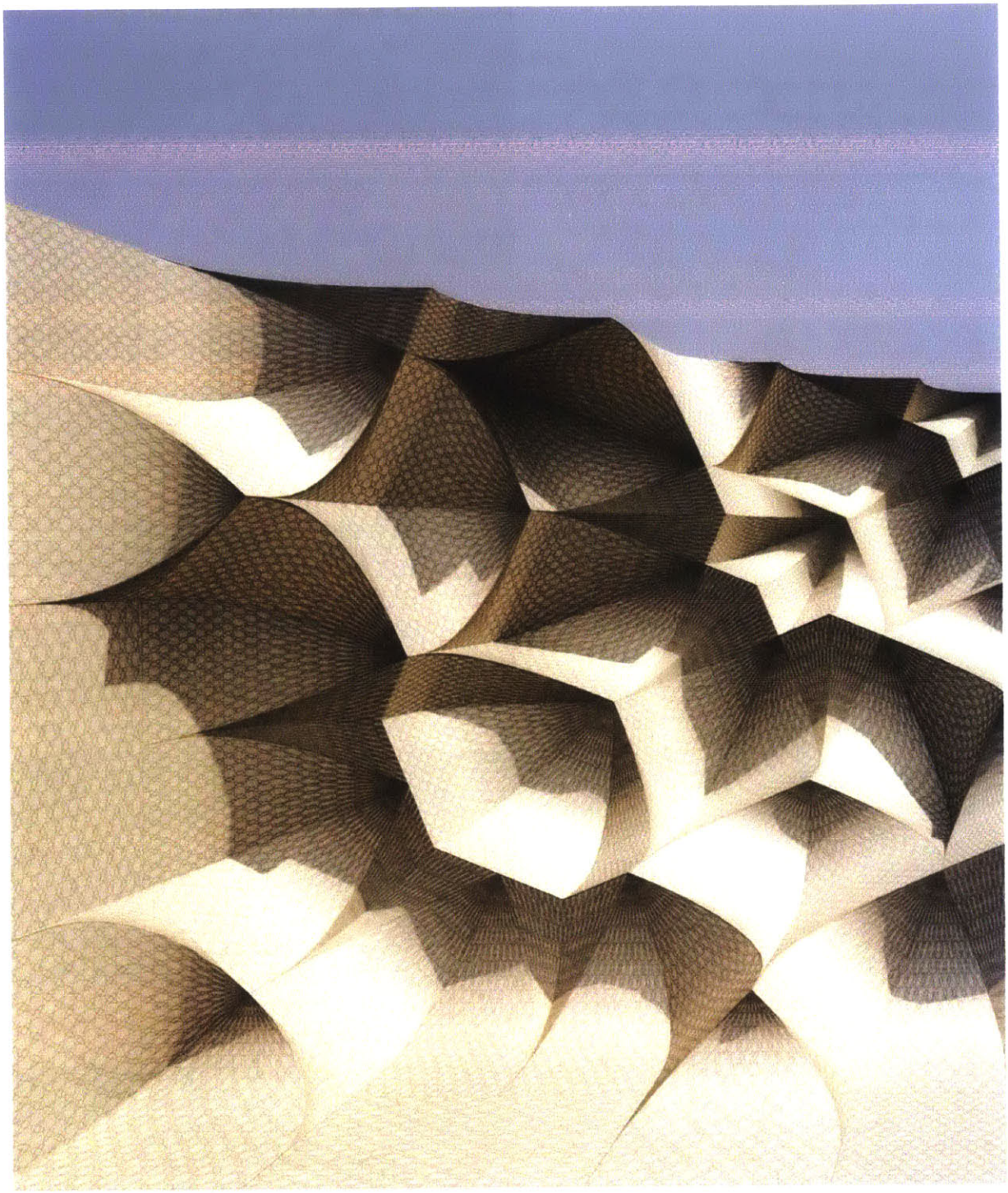
In the Area II, built environments are embellished with 3D printed components with higher resolution of ornament. There can be three different ways of increasing resolution; fractal, scaling, and densification

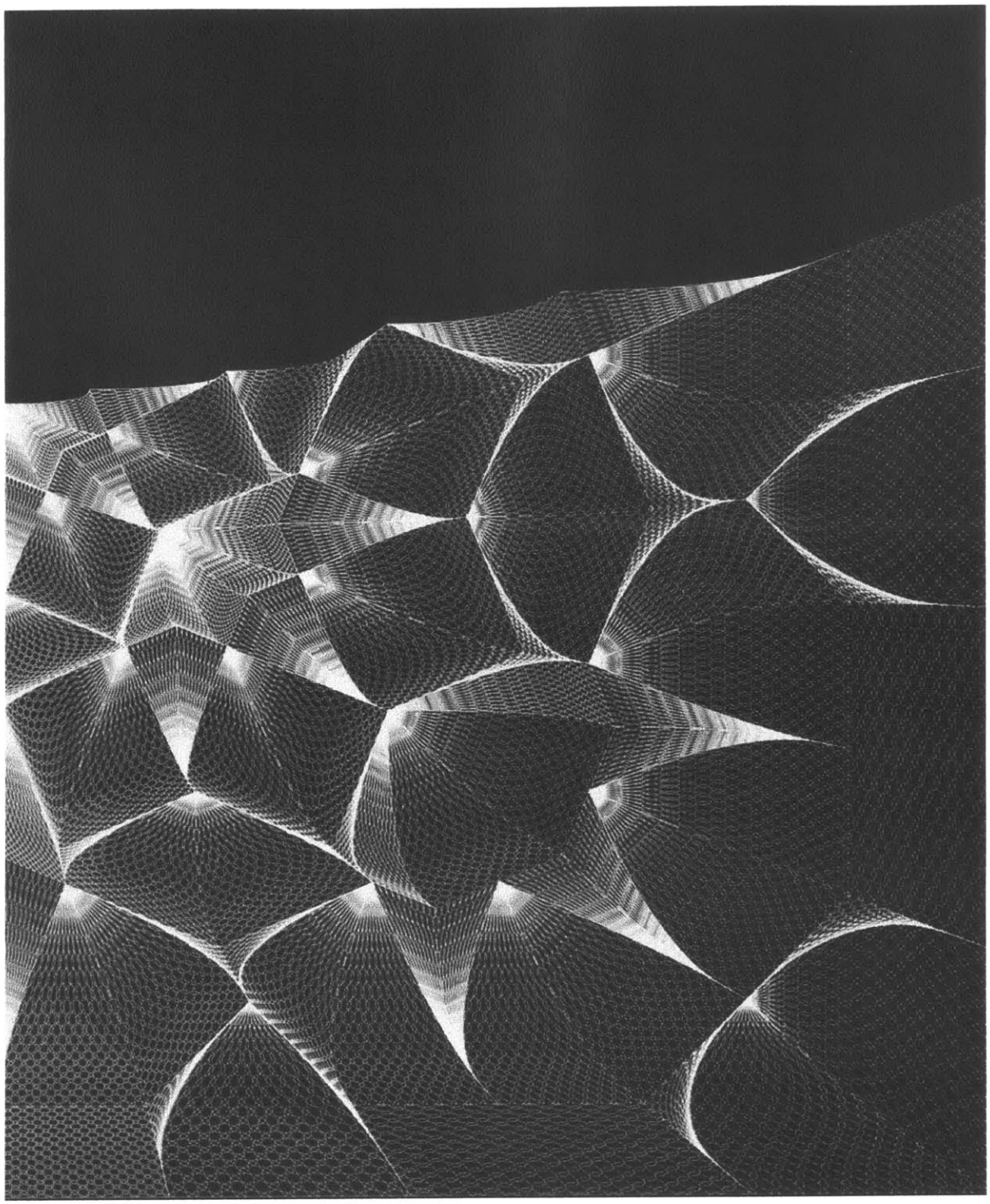


Fractal Repeatition of Ornament

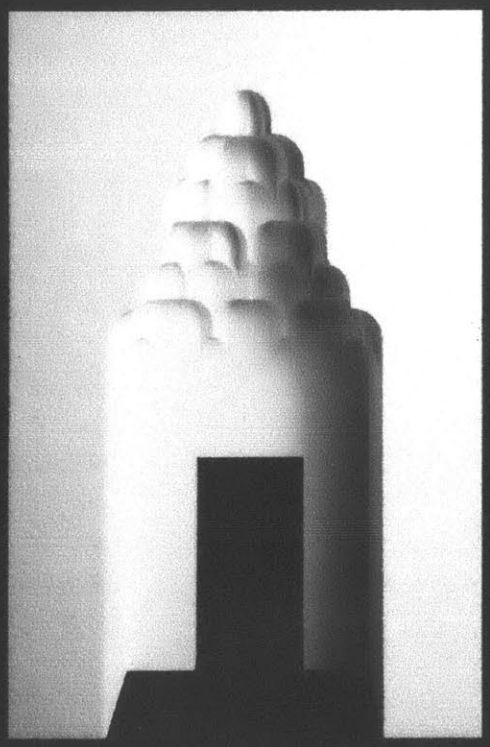


Scaling Down Elements



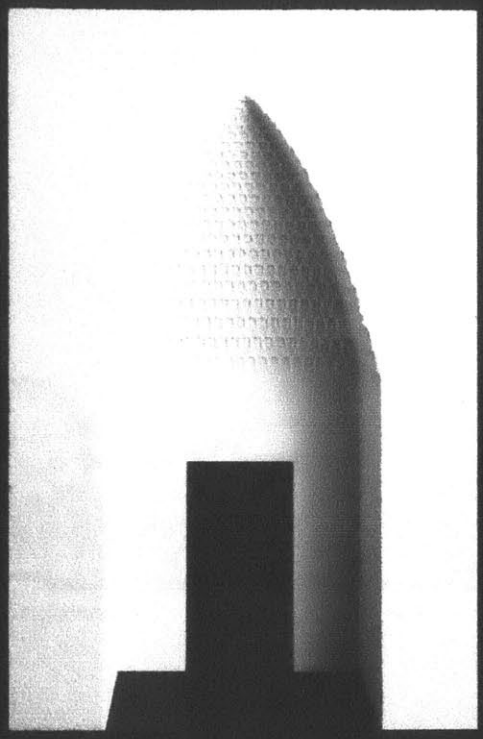


Densification of Ornament Pattern



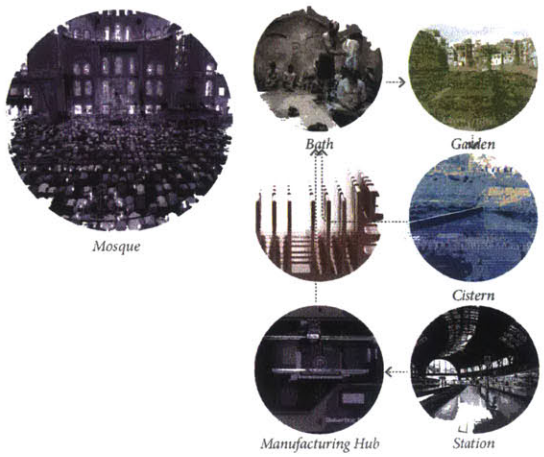
Muqarnas from an Existing Mosque

Muqarnas is an ornamental element that is found in islamic architecture mostly from mosques. It is regarded one of the most advanced craftsmanship skill to compose a muqarnas ornament. Depending on its complexity, it consists of three to six different elements in general.

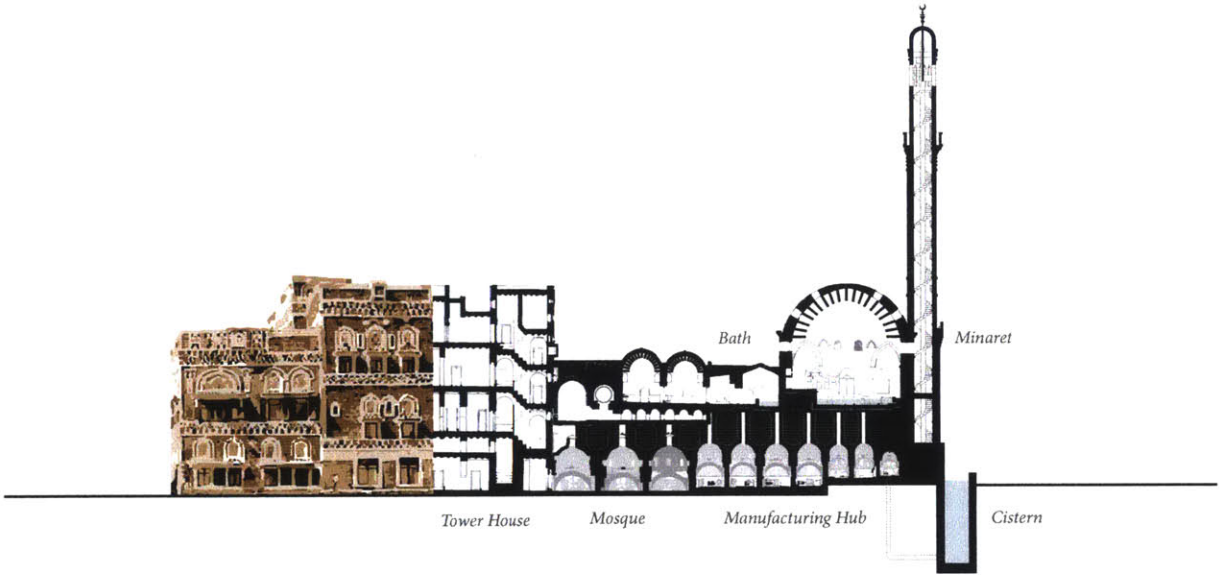


Muqarnas with Scaled Elements

As a way of increasing resolution of an ornament, scaling operation can be used, which can't be done by handicraft but only by digital and 3D printing technology.



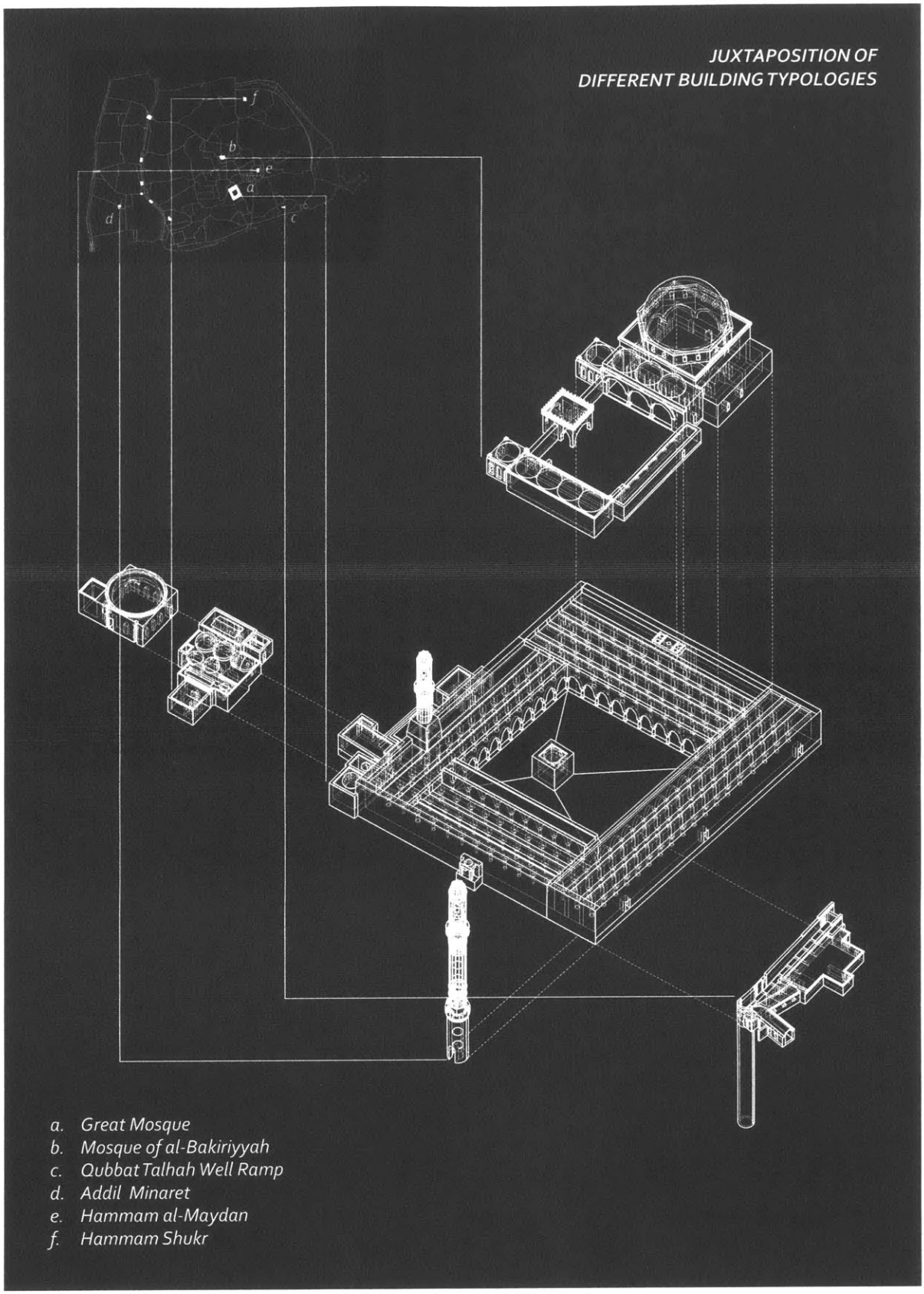
Re-connection of
Different Building Typologies of Sana'a

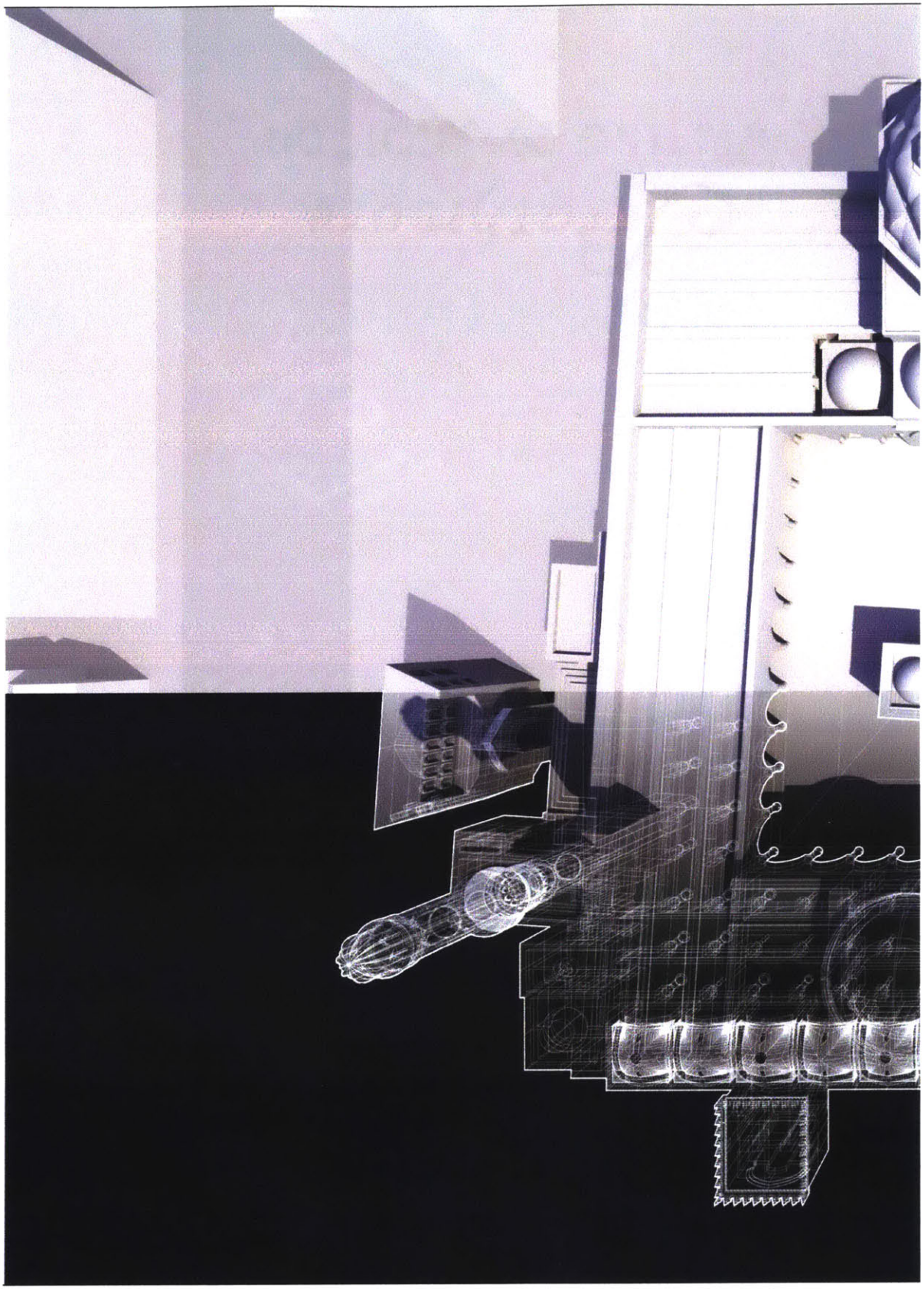


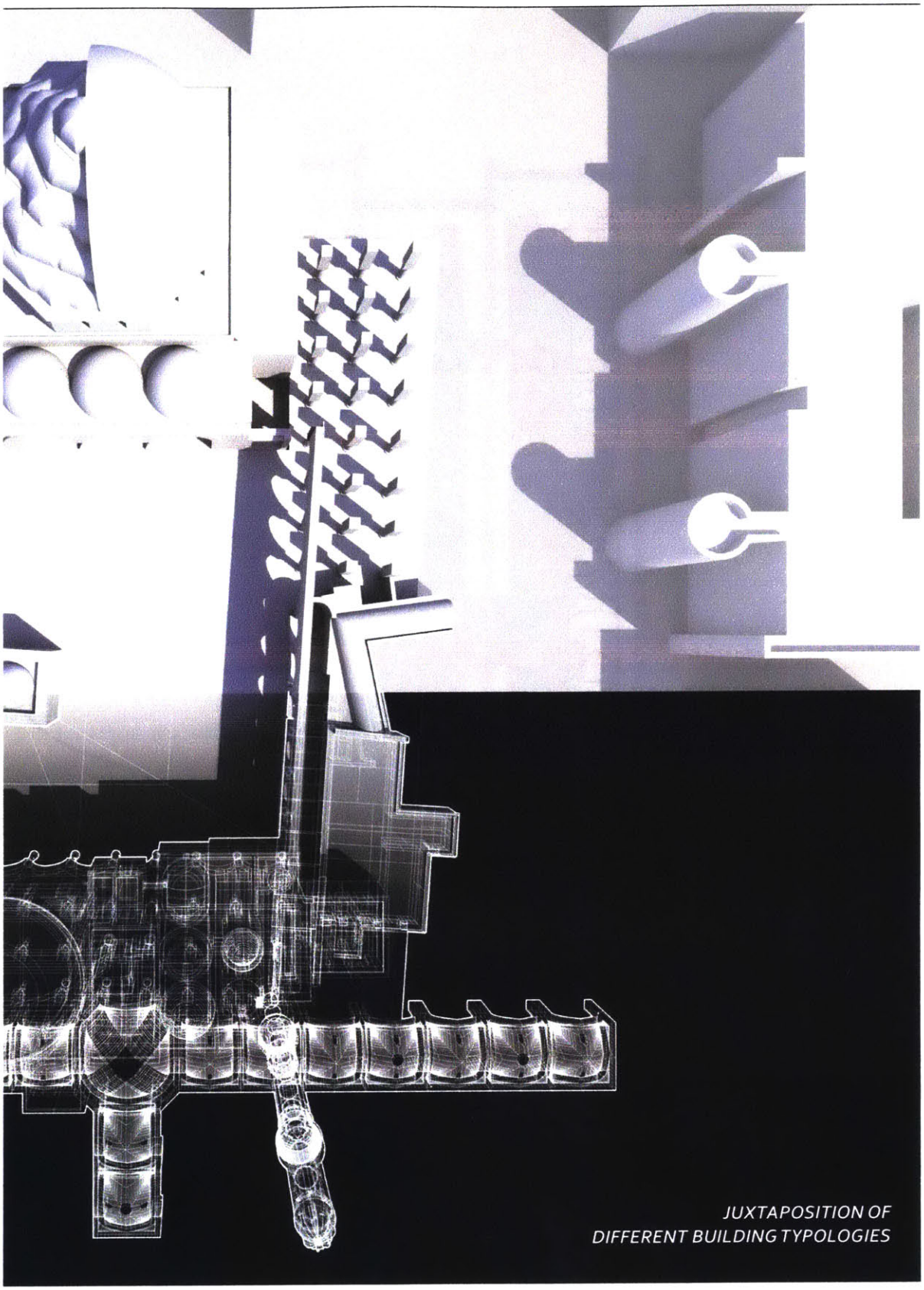
AREA III

Juxtaposition

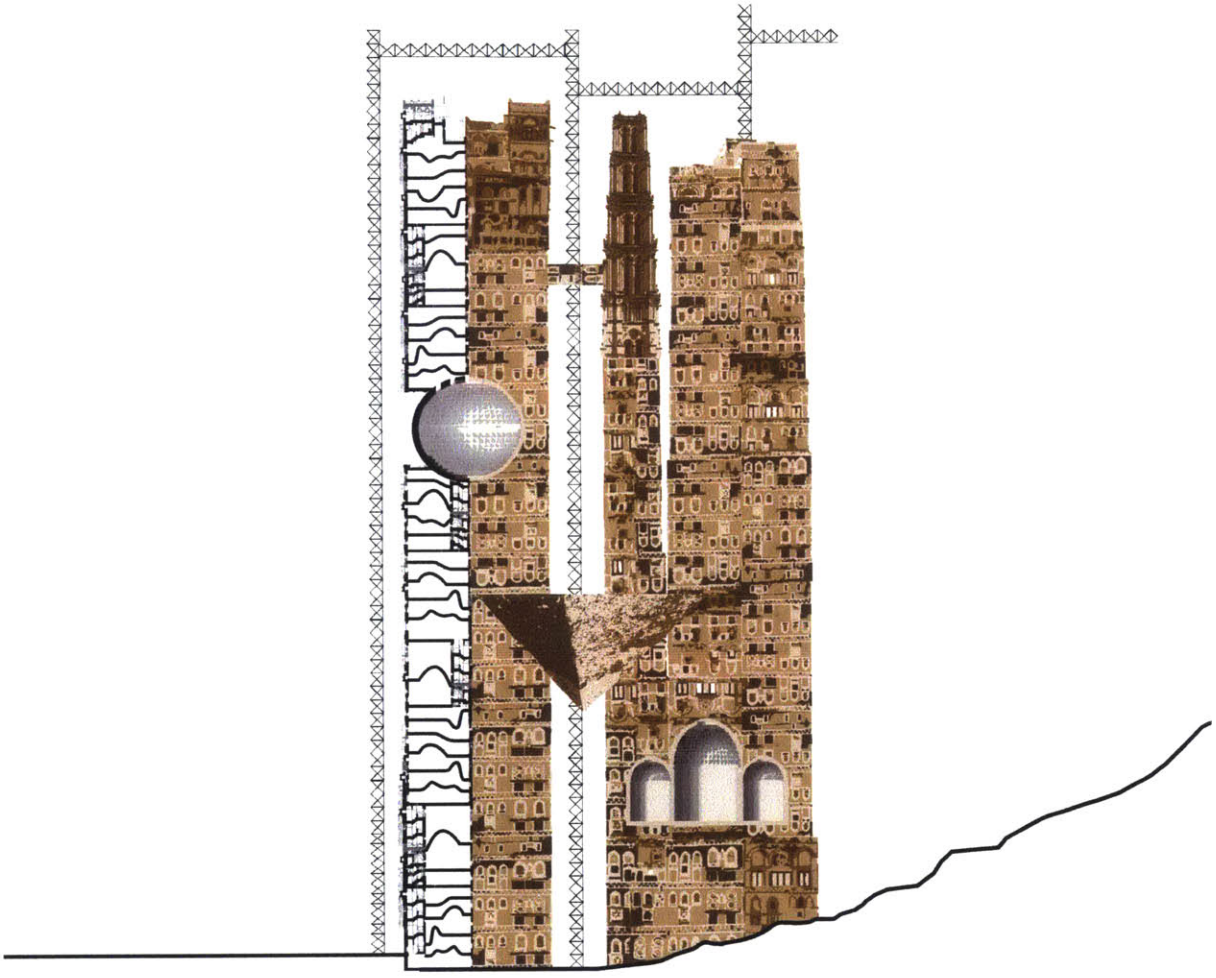
In the Typological blend area, multiple building typologies and functions are merged, maintaining their own typological features. This as a complex constitutes a manufacturing hub. Traditional building materials are used to construct this area.


JUXTAPOSITION OF
DIFFERENT BUILDING TYPOLOGIES
a. Great Mosque
b. Mosque of al-Bakiriyyah
c. Qubbat Talhah Well Ramp
d. Addil Minaret
e. Hammam al-Maydan
f. Hammam Shukr





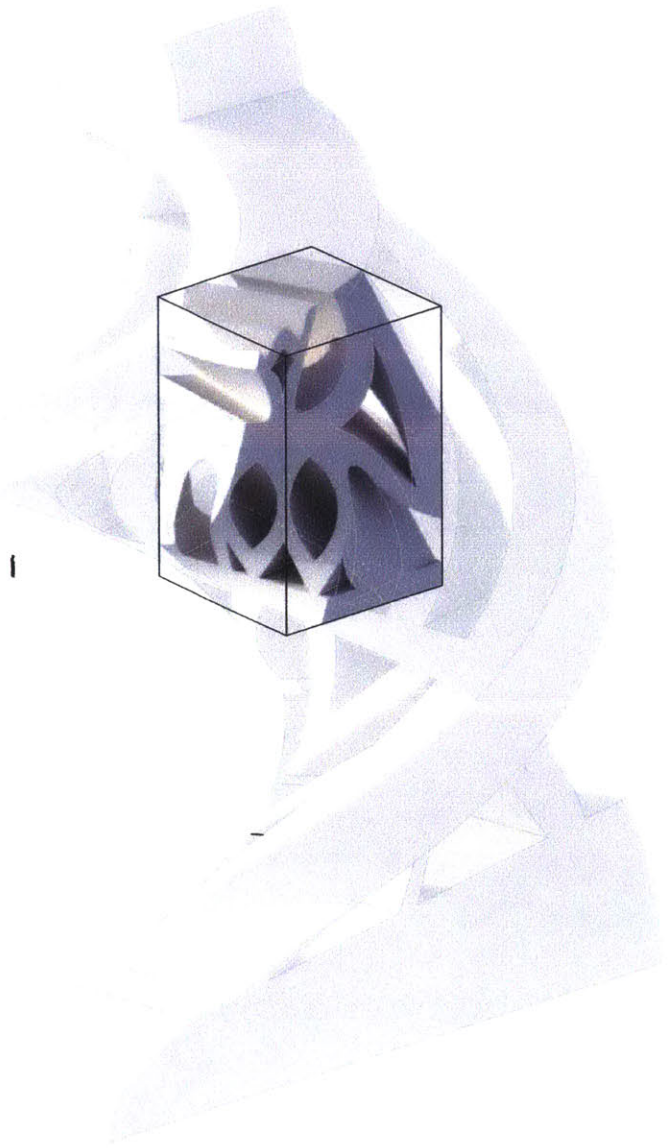
JUXTAPOSITION OF
DIFFERENT BUILDING TYPOLOGIES



AREA IV

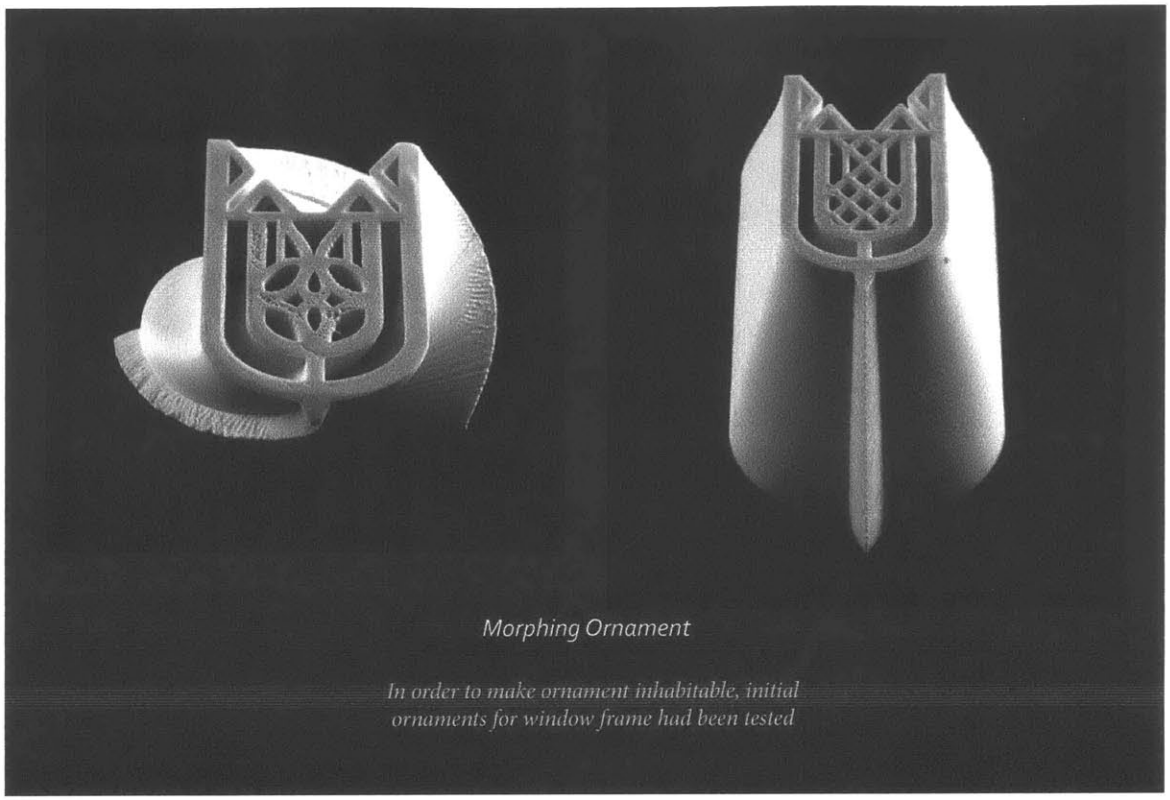
Inhabitable Ornament

In the Inhabitable Ornament area, part of ornament scaled and morphed so that it becomes large enough to inhabit inside. Thus, people have intimate relationships with ornament, becoming part of it.



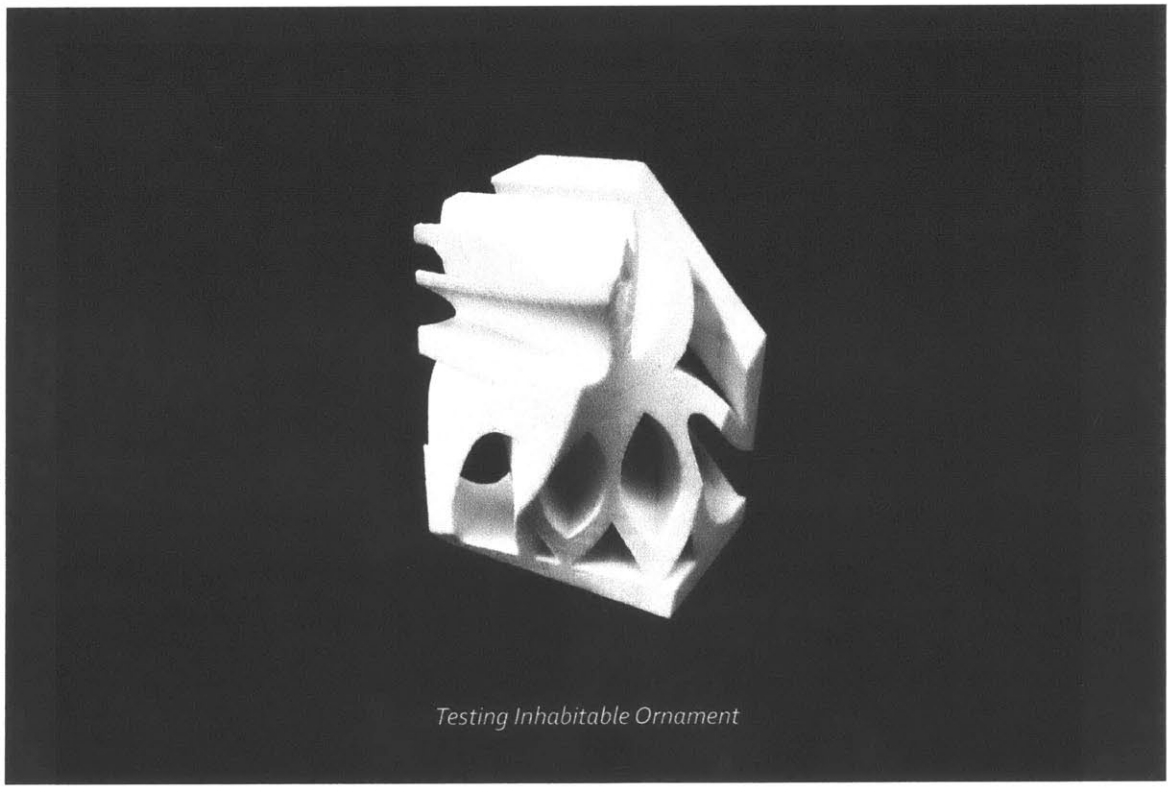
ADDING ONE DIMENSION TO A FLAT ORNAMENT

A series of morphing operations, including scaling, twisting, and tapering, adds one dimension to a flat or two dimensional ornament, as well as makes it inhabitable

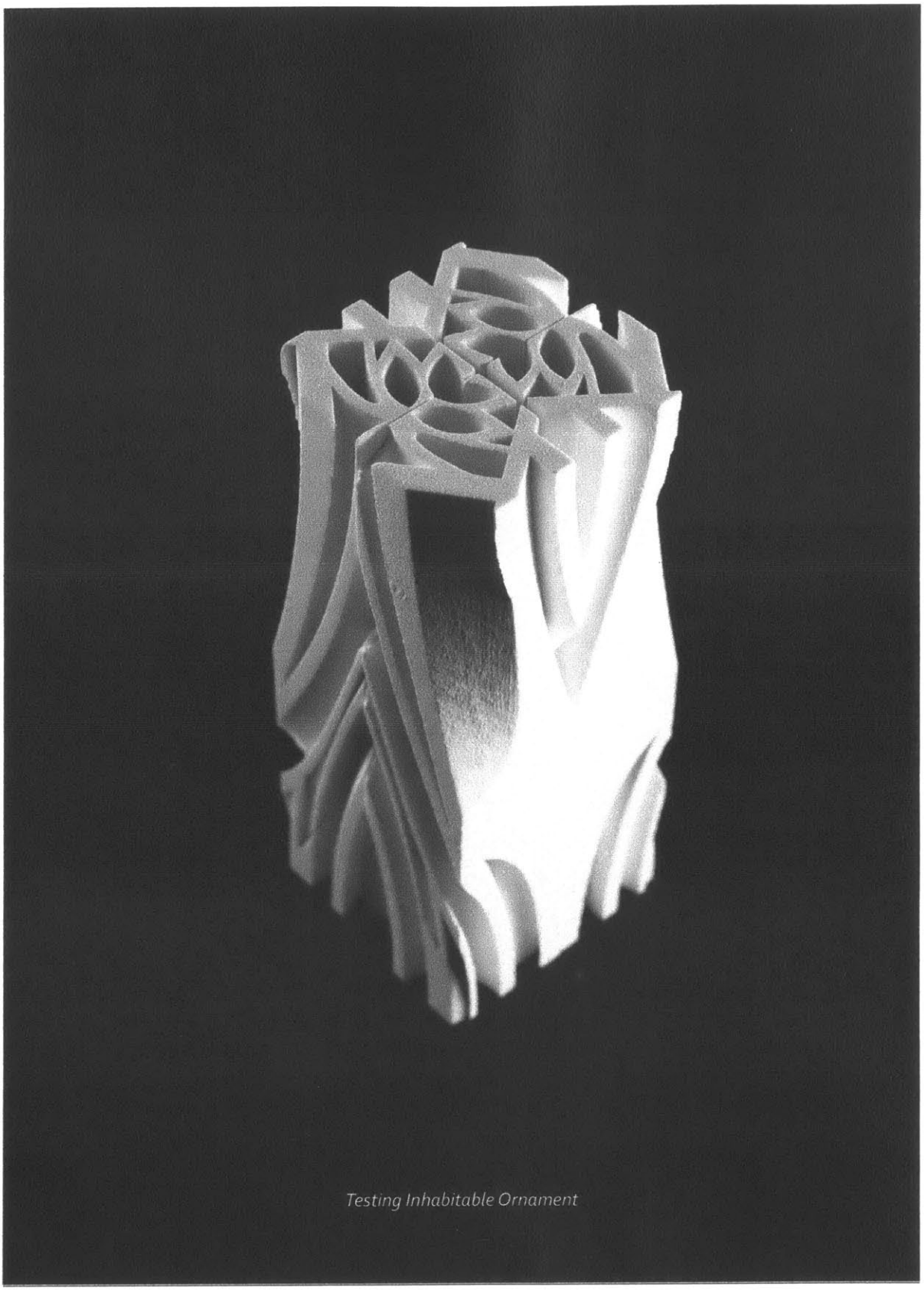


Morphing Ornament

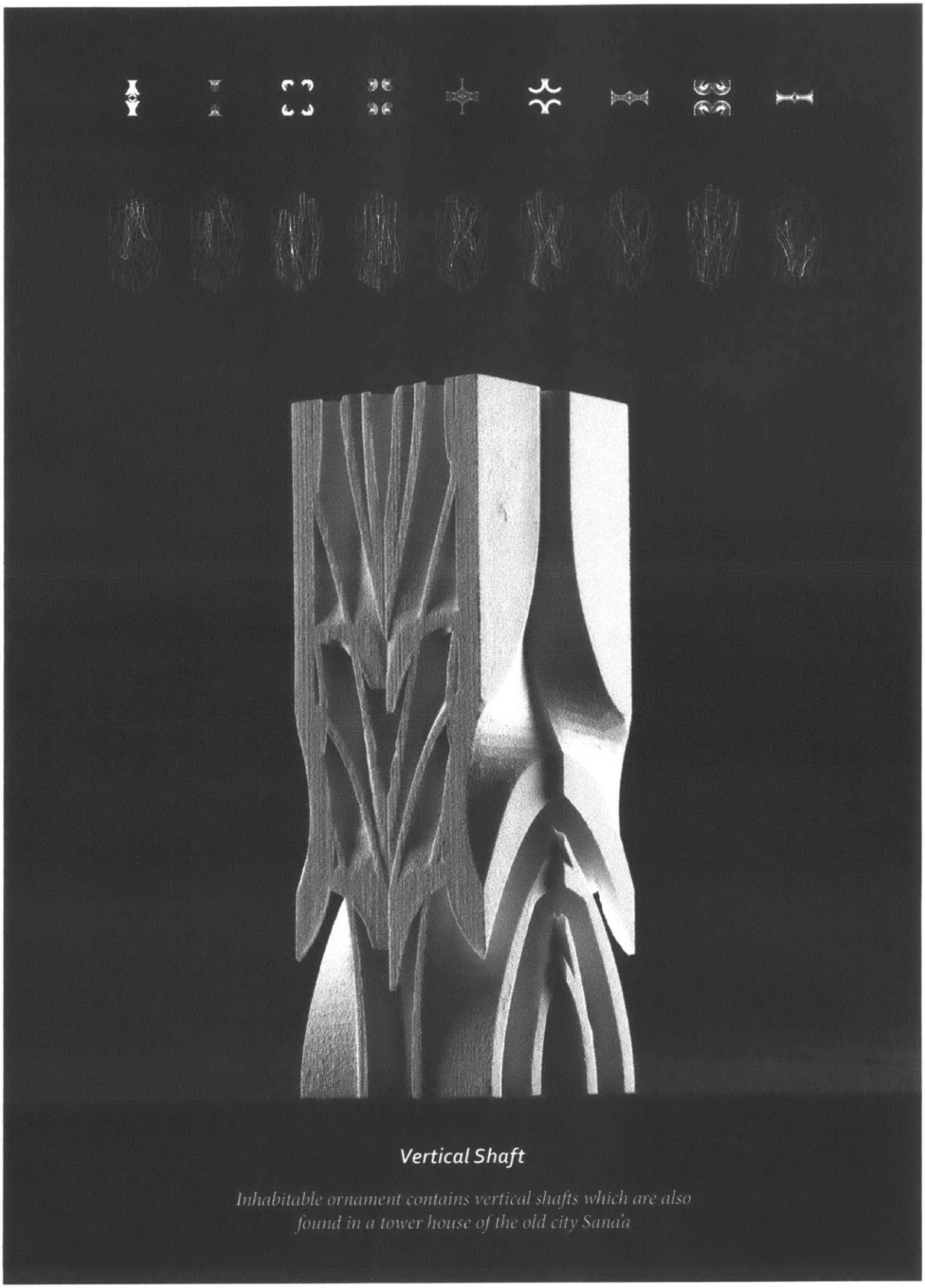
In order to make ornament inhabitable, initial ornaments for window frame had been tested



Testing Inhabitable Ornament

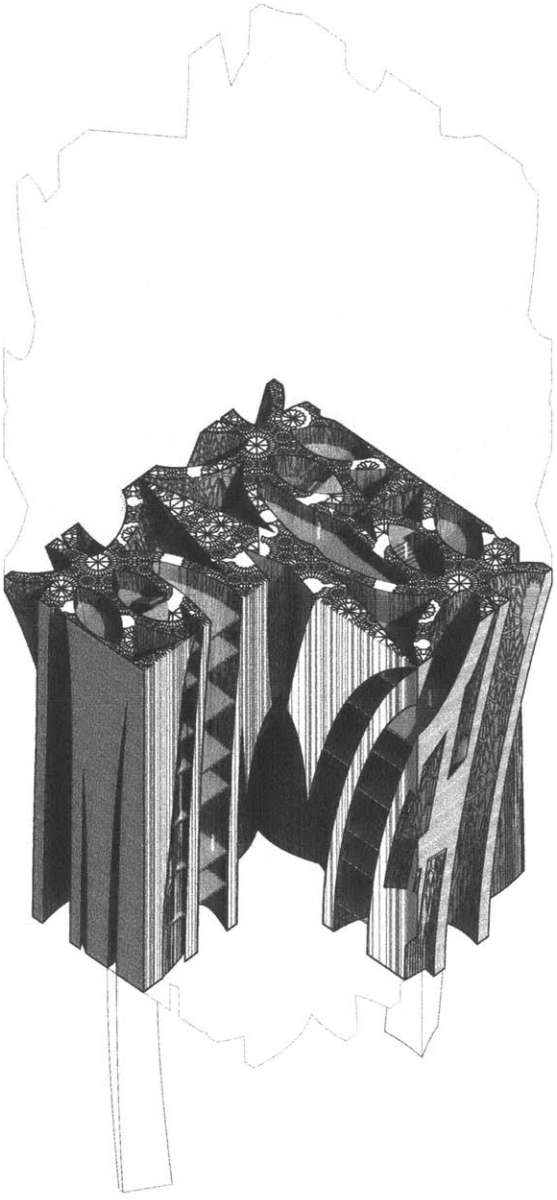


Testing Inhabitable Ornament



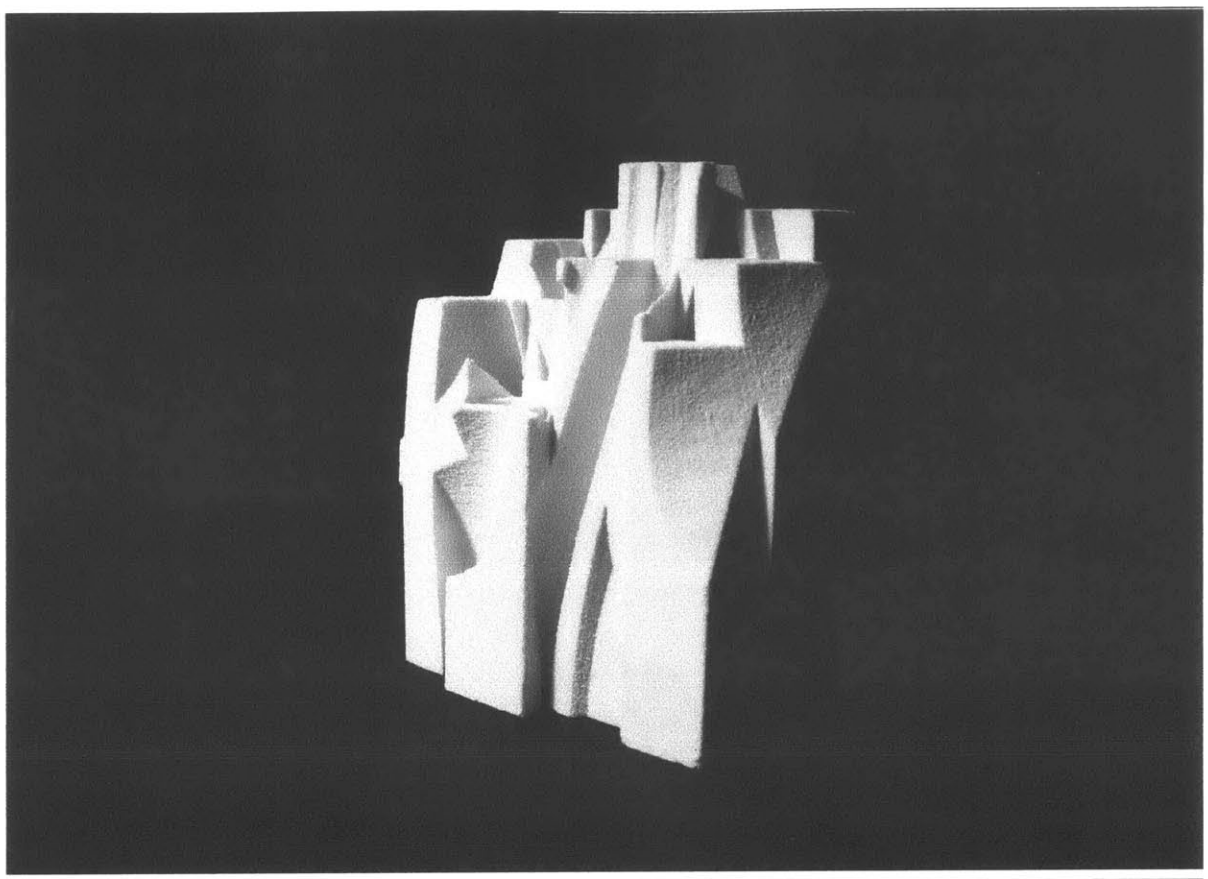
Vertical Shaft

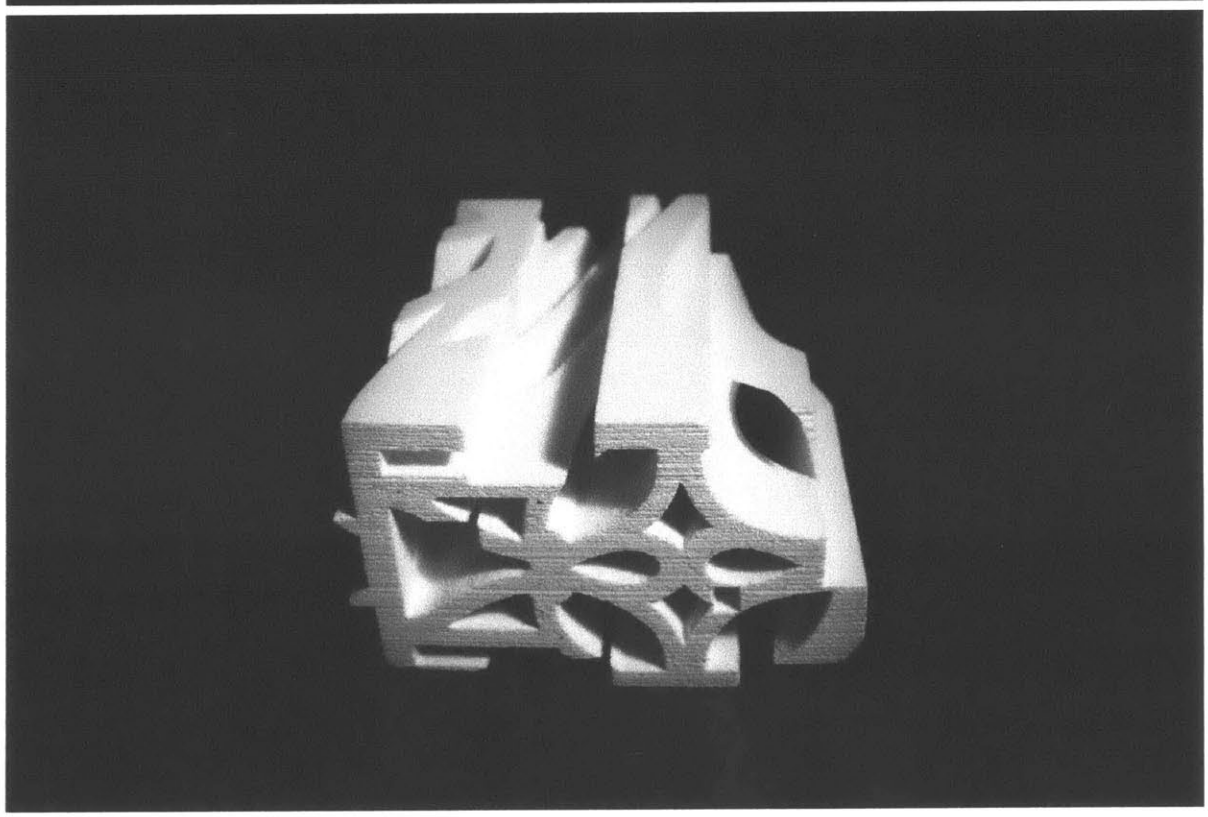
Inhabitable ornament contains vertical shafts which are also found in a tower house of the old city Sana'a

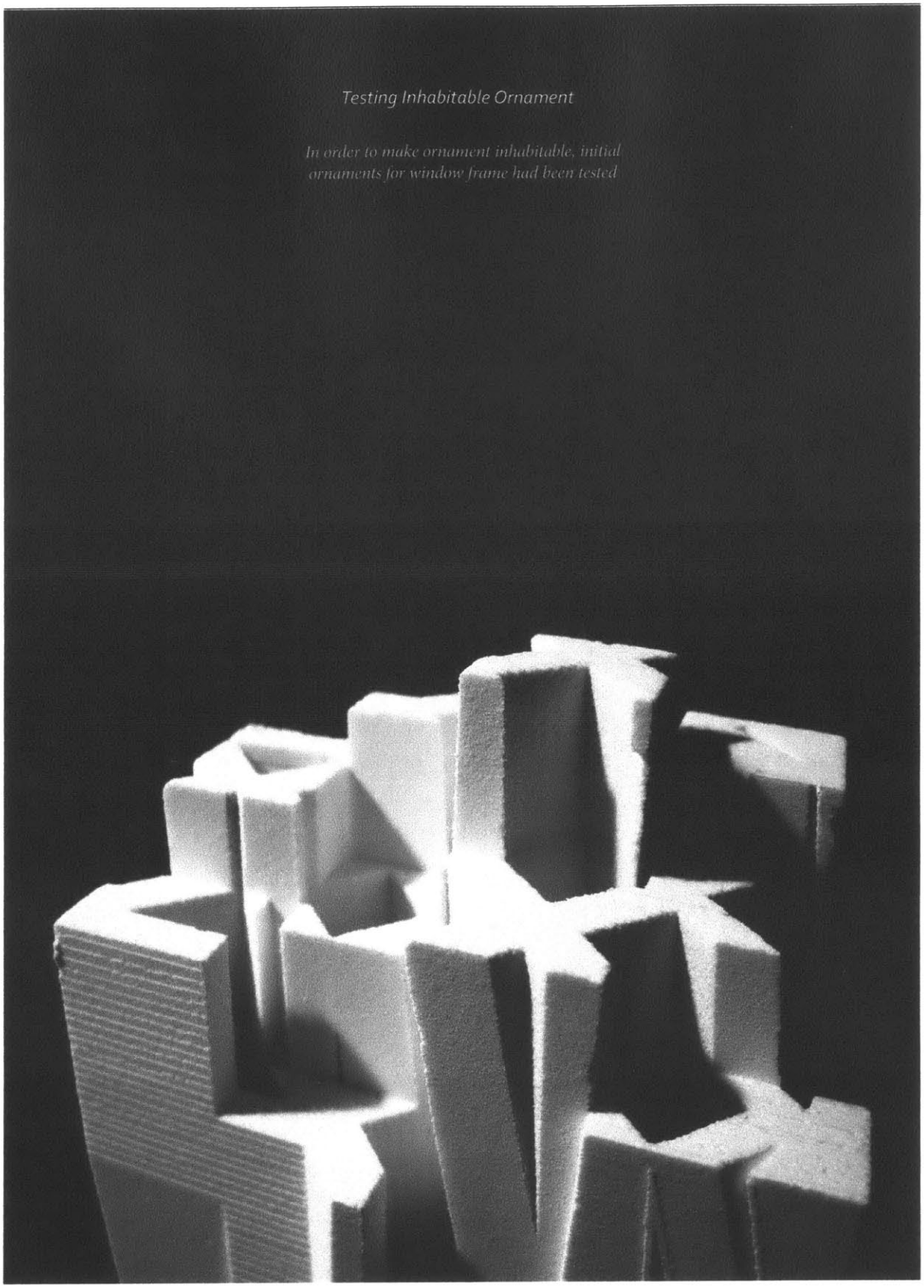


Volumetric Ornament

Ornament is found not only in elevation but also in plan and section

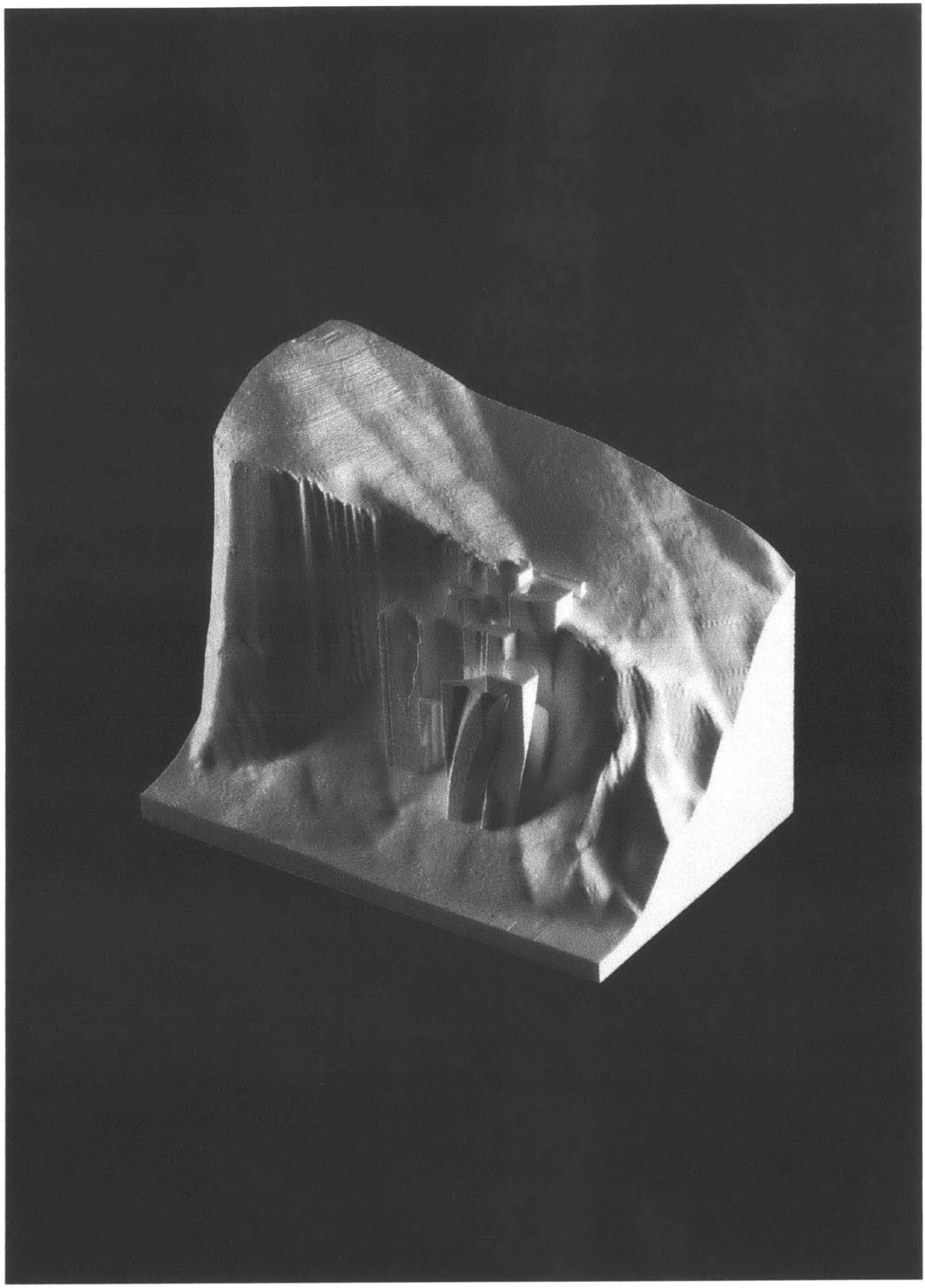


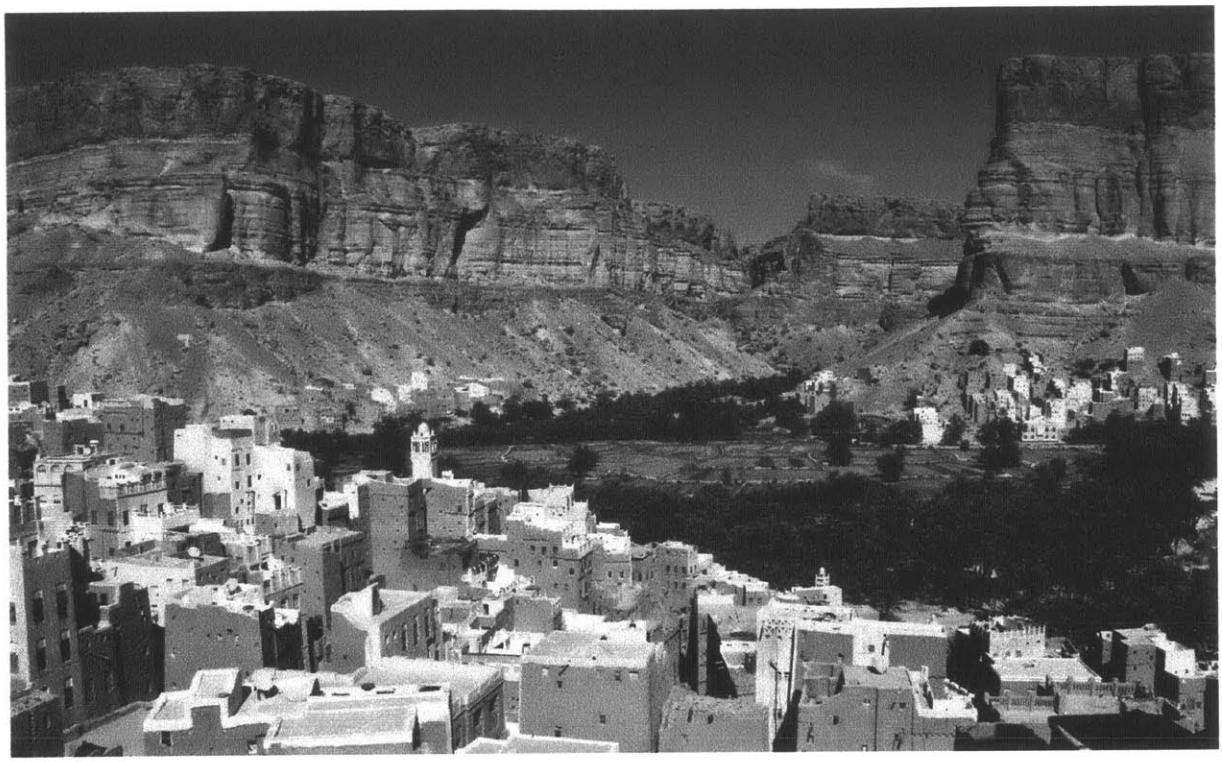




Testing Inhabitable Ornament

In order to make ornament inhabitable, initial ornaments for window frame had been tested



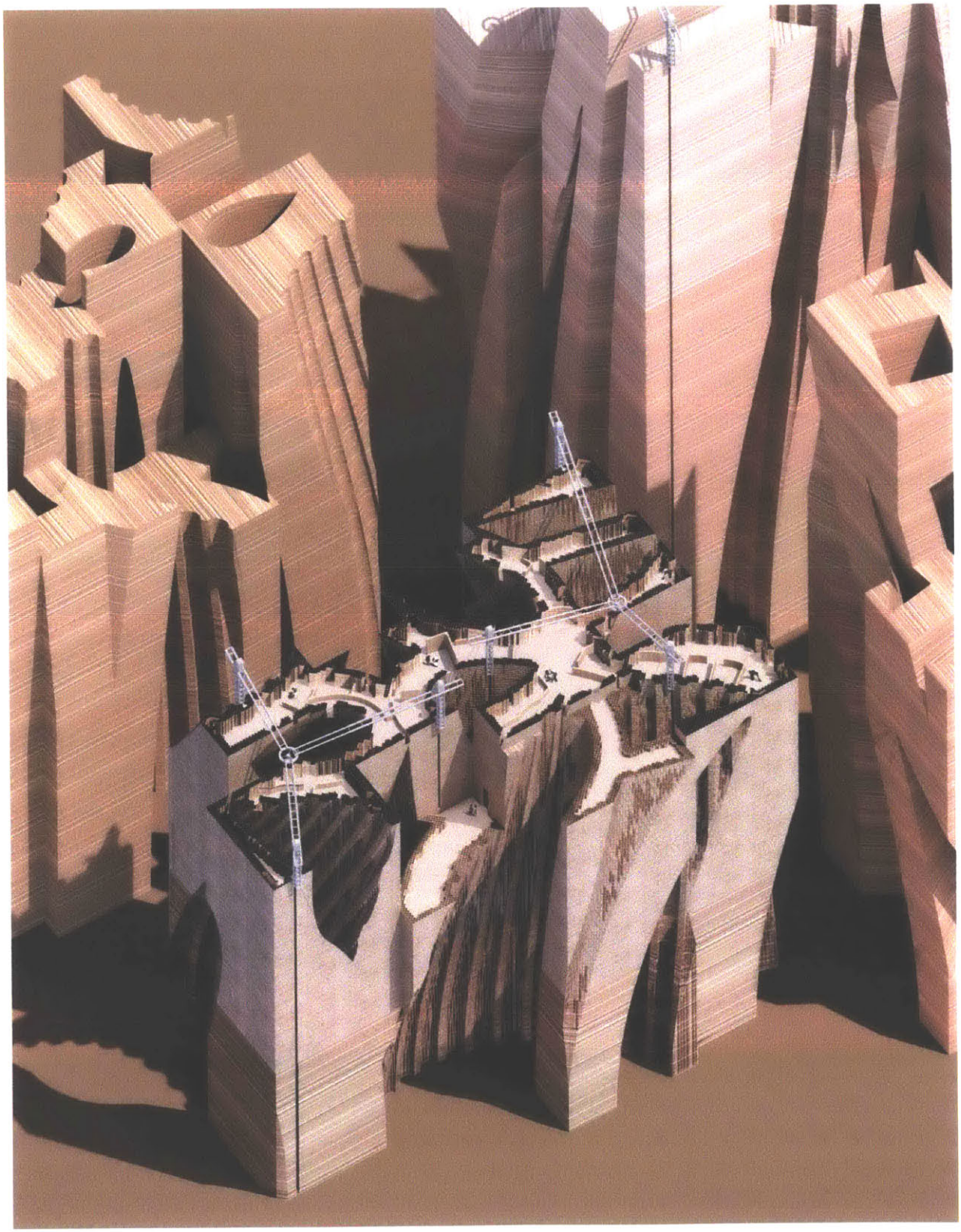


VERNACULAR ORNAMENT

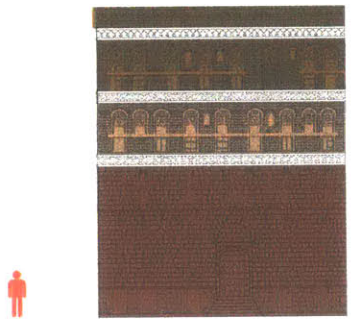
3D printed Inhabitable Ornament is vernacular in that it resembles the features of topography of Sana'a.
In Yemen, many cities have rocky mountains which gave a birth to a Tower House building typology.

Left_Conceptual Model of Inhabitable Ornament Embedded in Topography

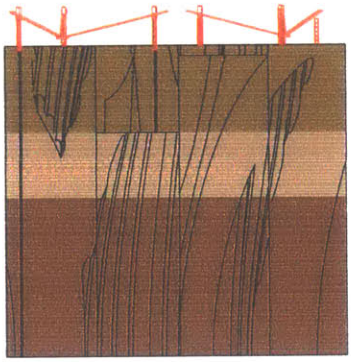
Inhabitable Ornament
site plan



Tower House in the Old City Sana'a



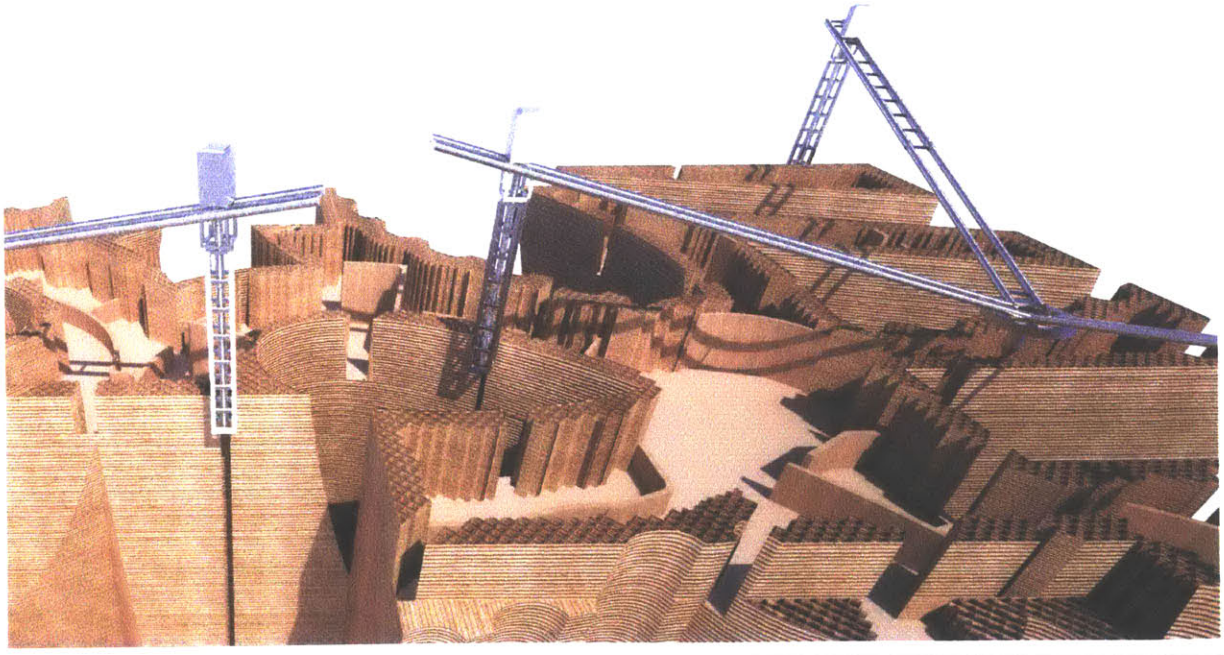
Inhabitable Ornament



TECTONICS

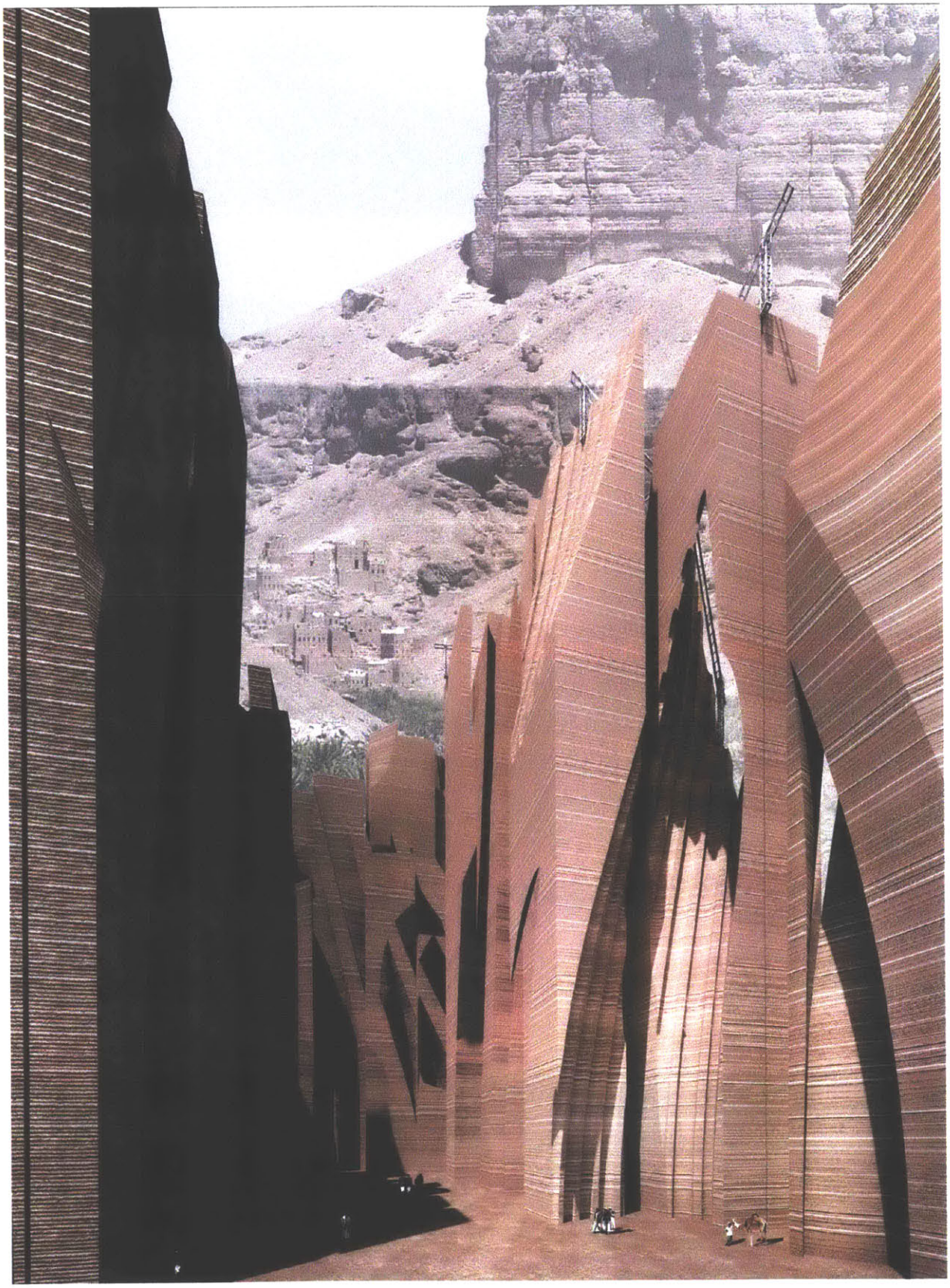
Vertical Addition over Time

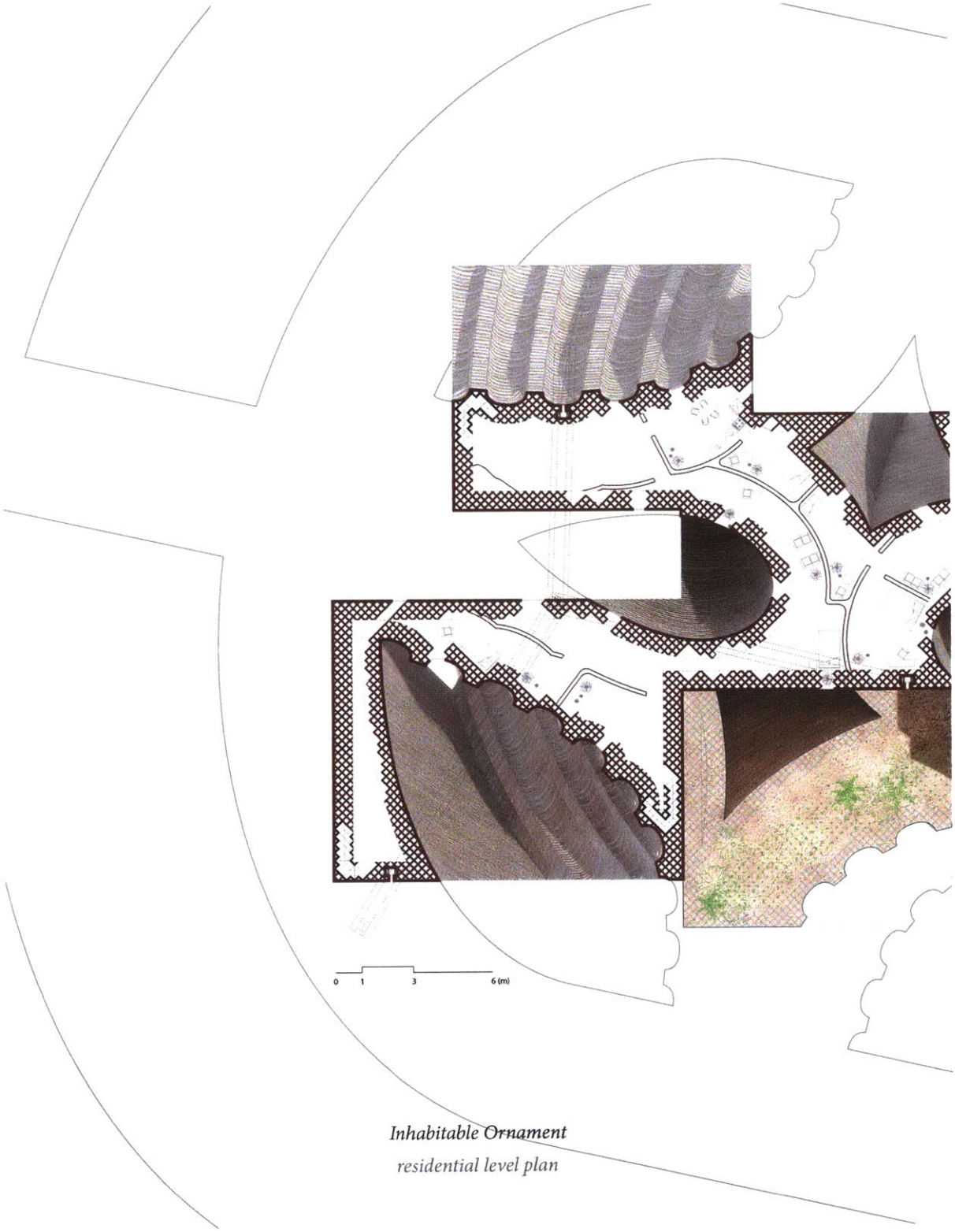
The way an Inhabitable Ornament is constructed resembles the way a Tower House in the old city had been built. 3D printers that climb up the clay surface are moving vertically along the rails and add materials on top of each other. And more levels are added over time as more space is needed. Gaps between different time period is revealed, indicating the number of construction phases.



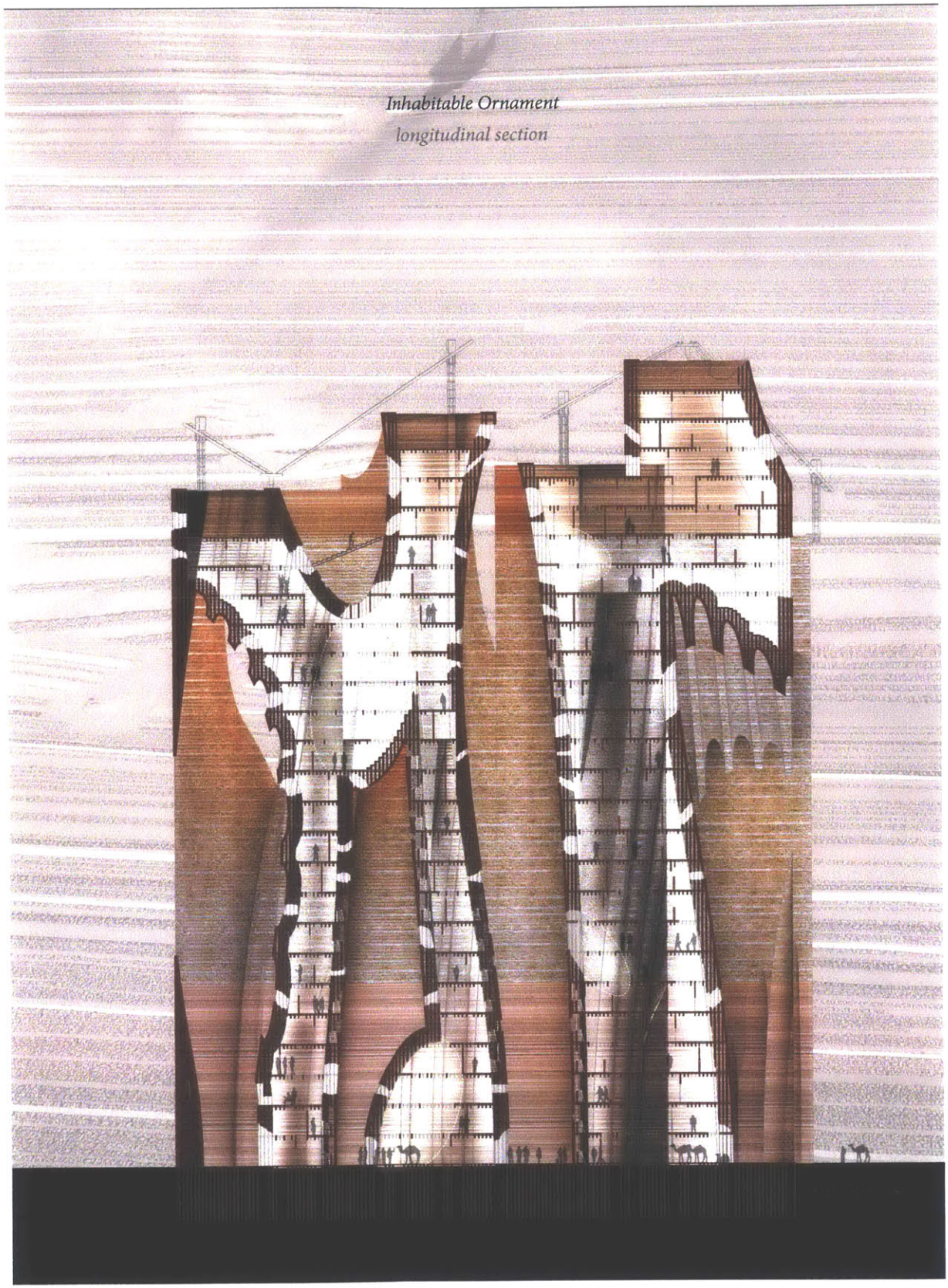
MONUMENTALITY

A cl.uster of 3D printed inhabitable ornament creates monumentality;
a six to eight-stories-high tower house turns into a thirty-stories high tower enabled by the new technology.

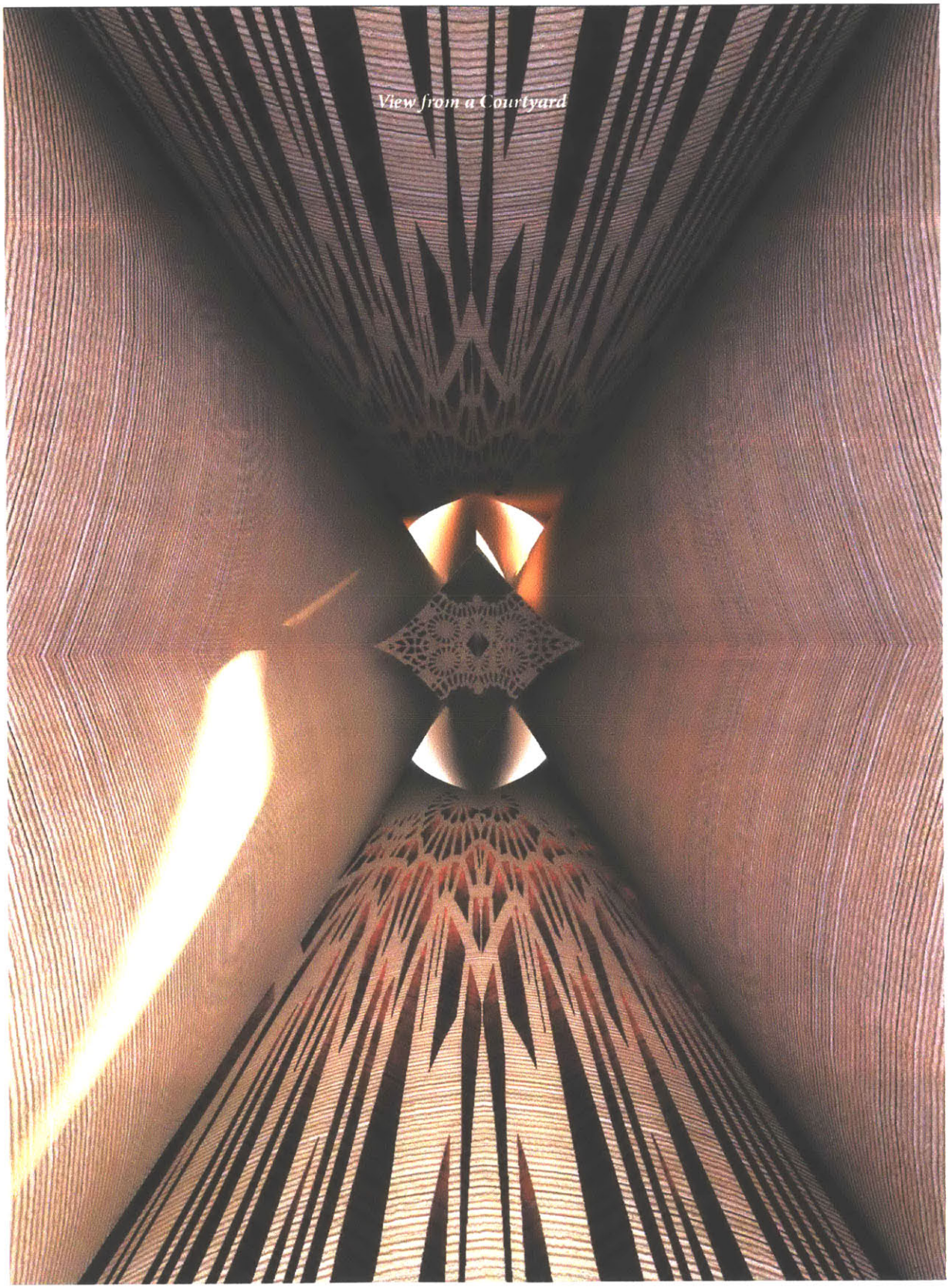


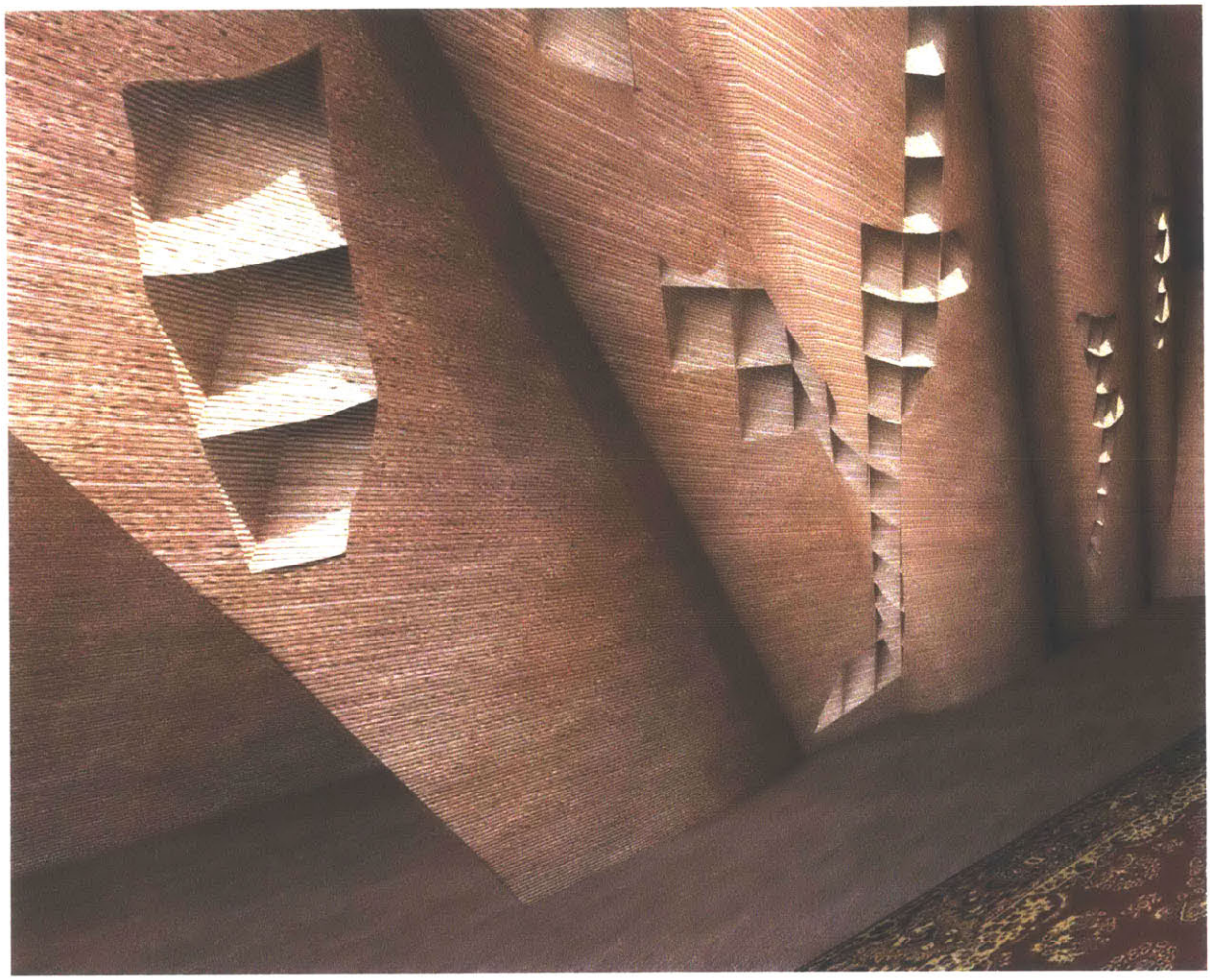


Inhabitable Ornament
residential level plan

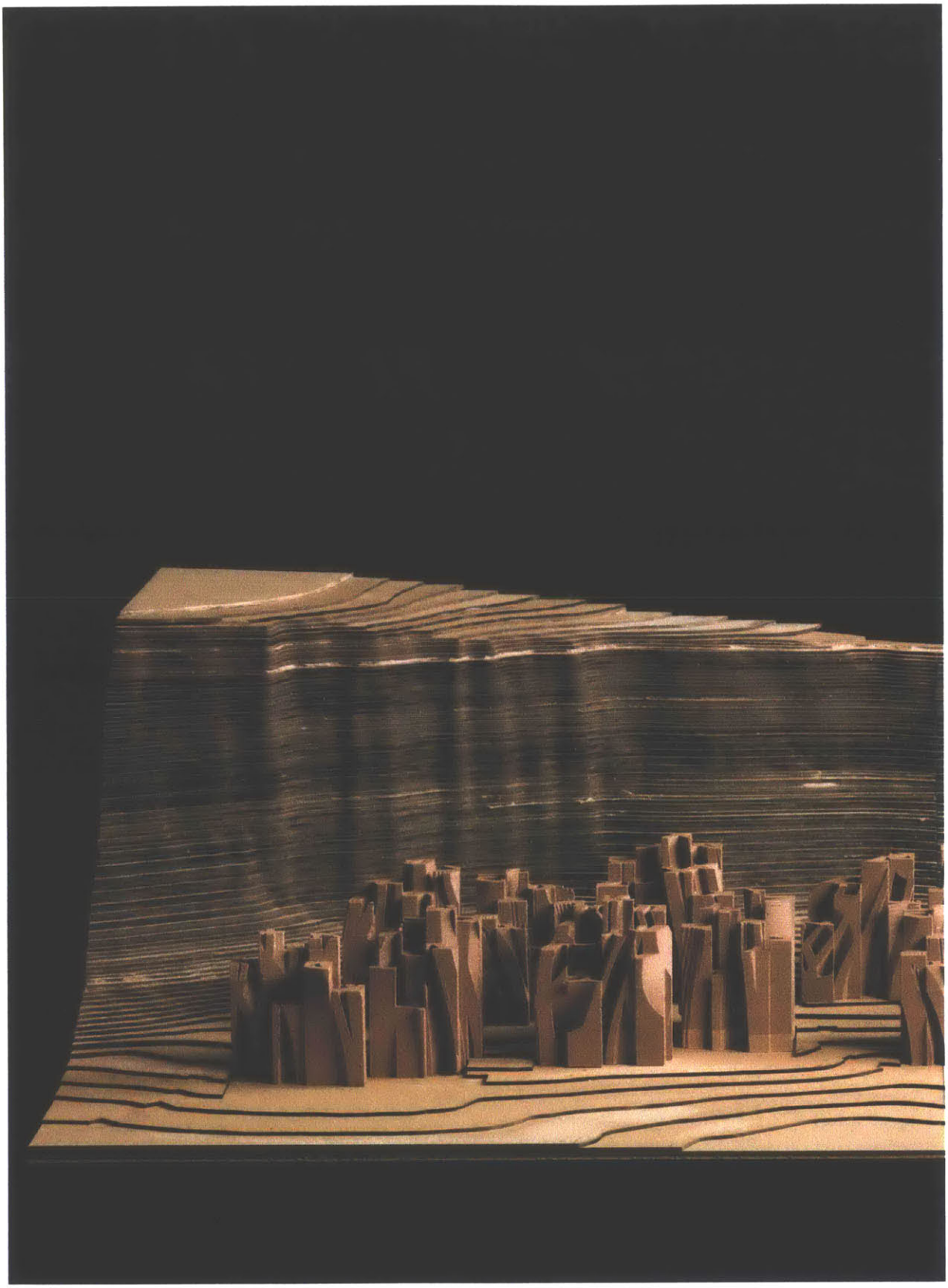


Inhabitable Ornament
longitudinal section


View from a Courtyard

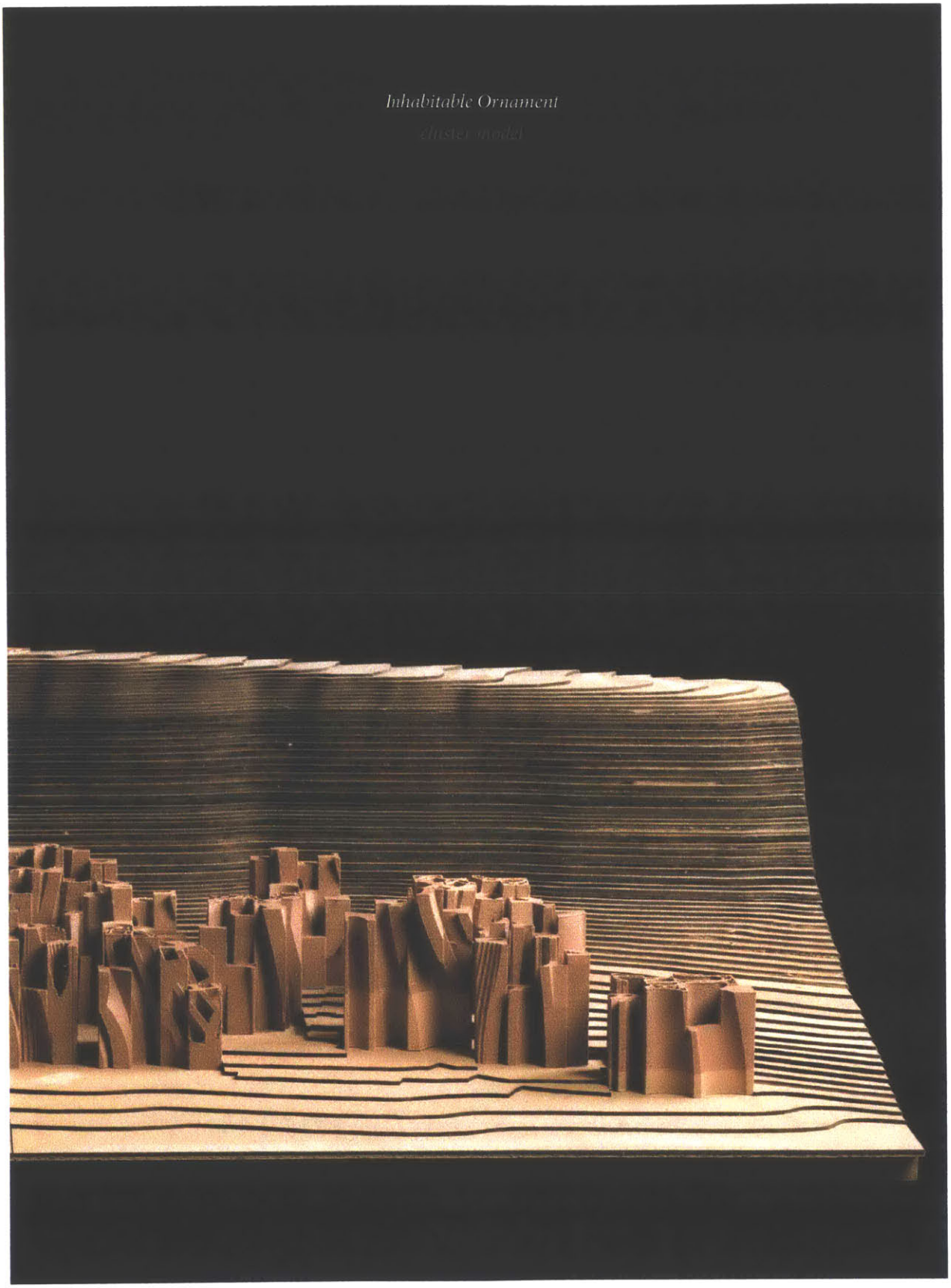


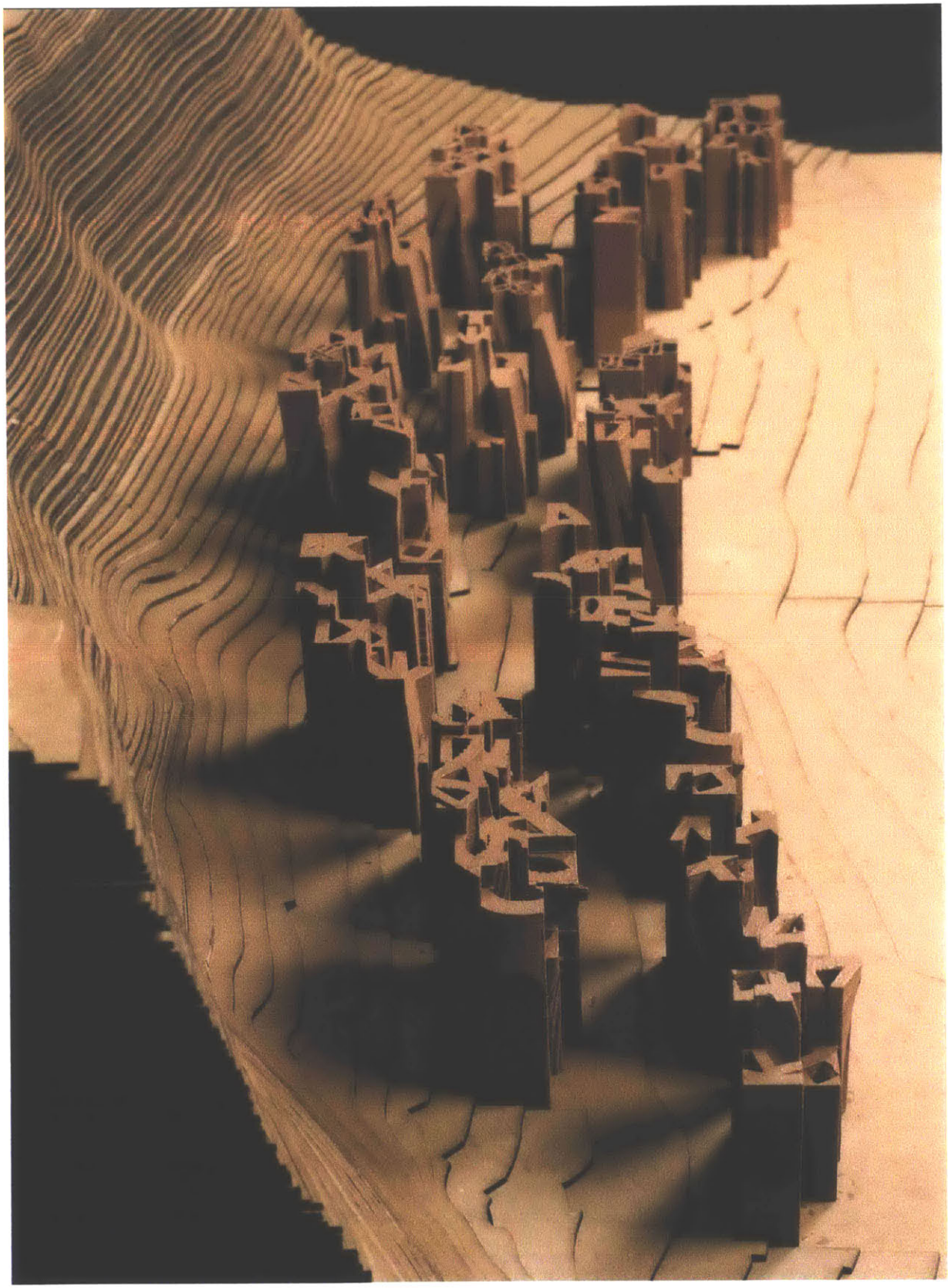
Interior Space Of Inhabitable Ornament



Inhabitable Ornament

Cluster model



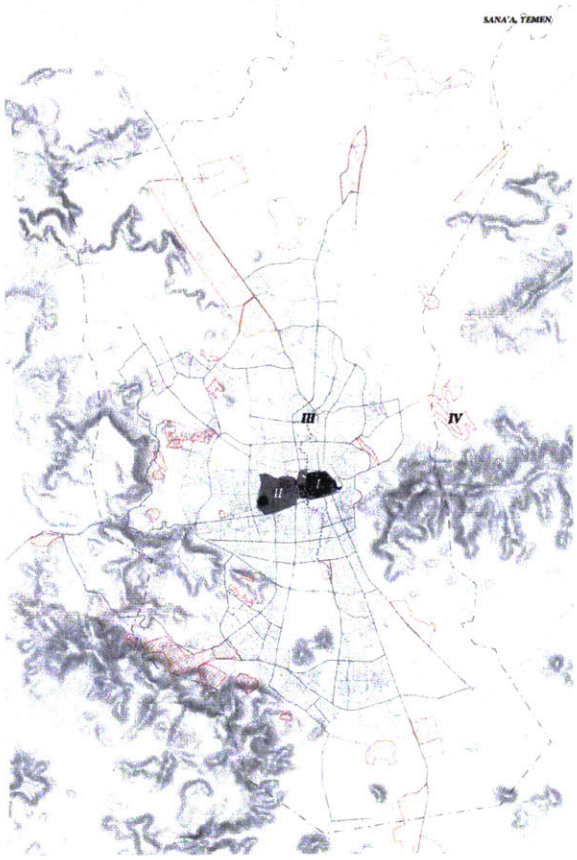


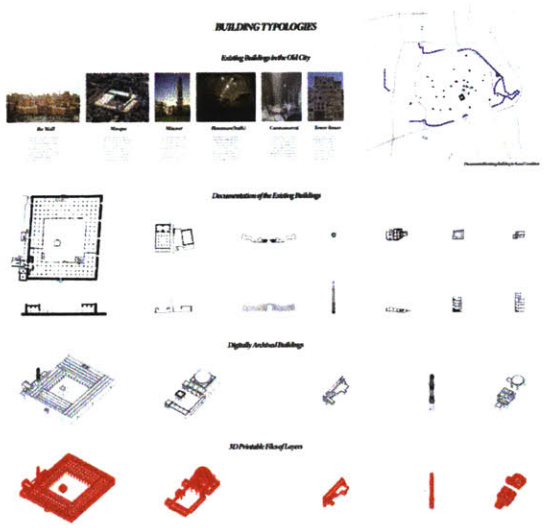
Inhabitable Ornament
cluster model

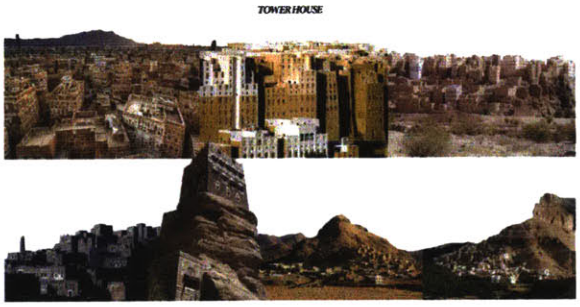
IV. APPENDIX

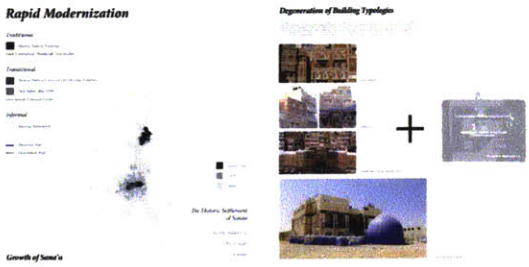
THESIS PRESENTATION

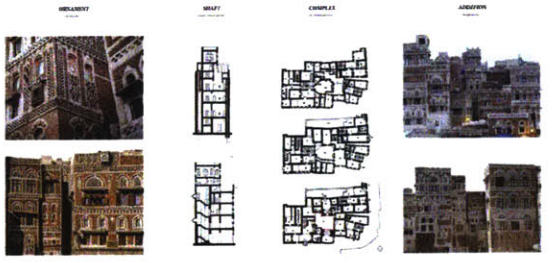
Thesis Presentation Boards

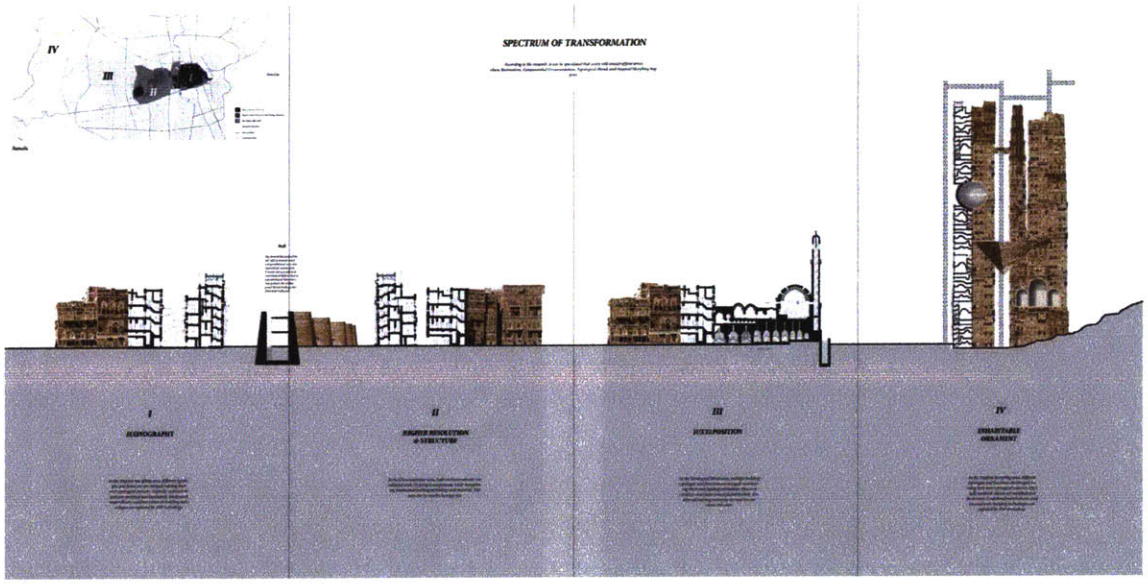


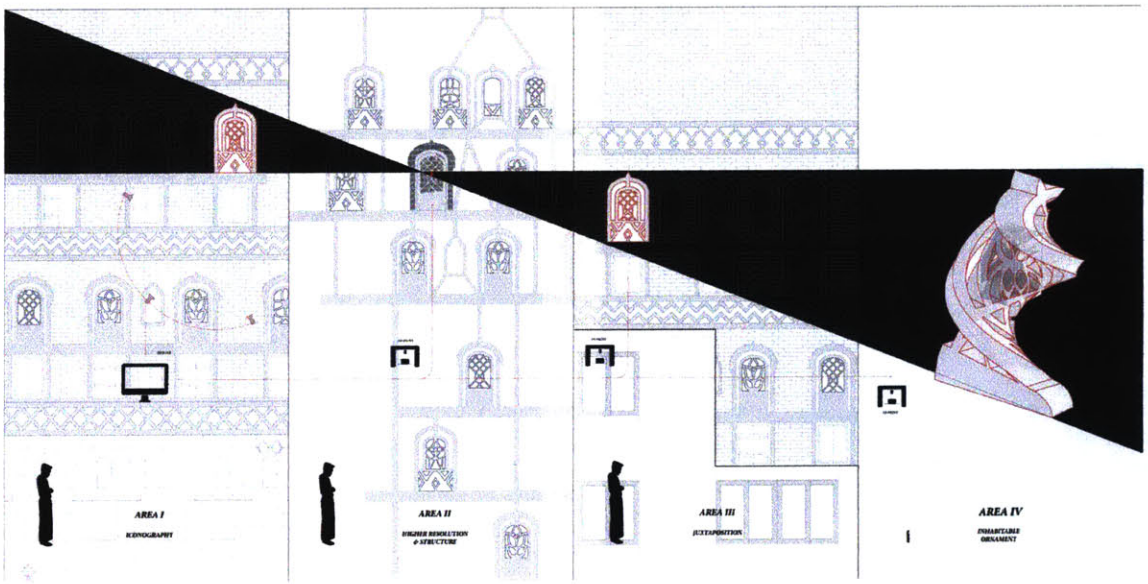


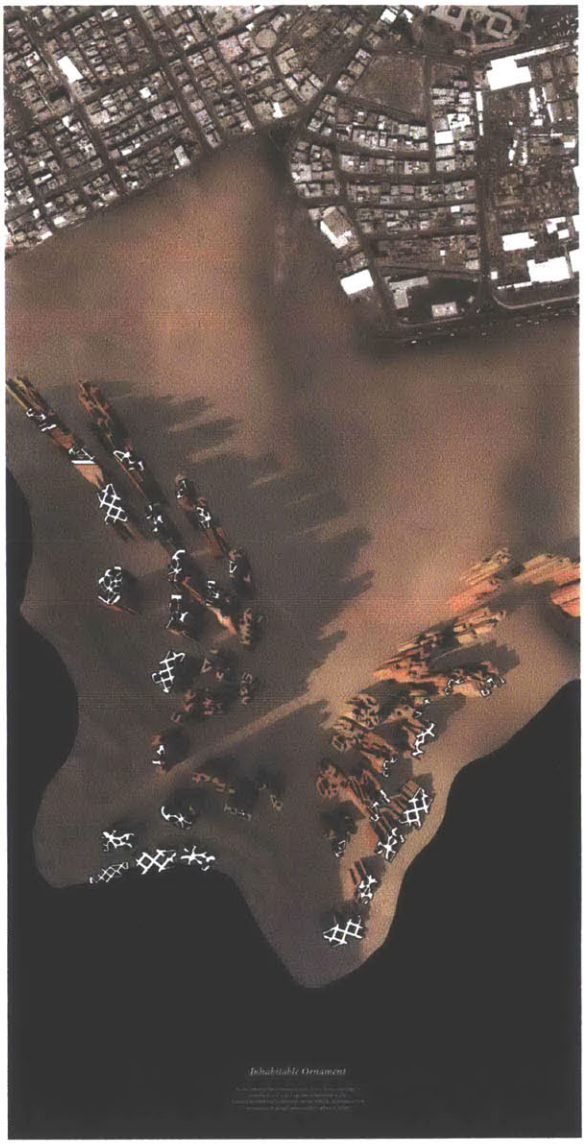







SPECTRUM OF TRANSFORMATION
IV
III
II
I
ICONOGRAPHY
II
HIGHER RESOLUTION & STRUCTURE
III
JUXTAPOSITION
IV
INHABITABLE ORNAMENT


AREA I
ICONOGRAPHY
AREA II
HIGHER RESOLUTION & STRUCTURE
AREA III
JUXTAPOSITION
AREA IV
INHABITABLE ORNAMENT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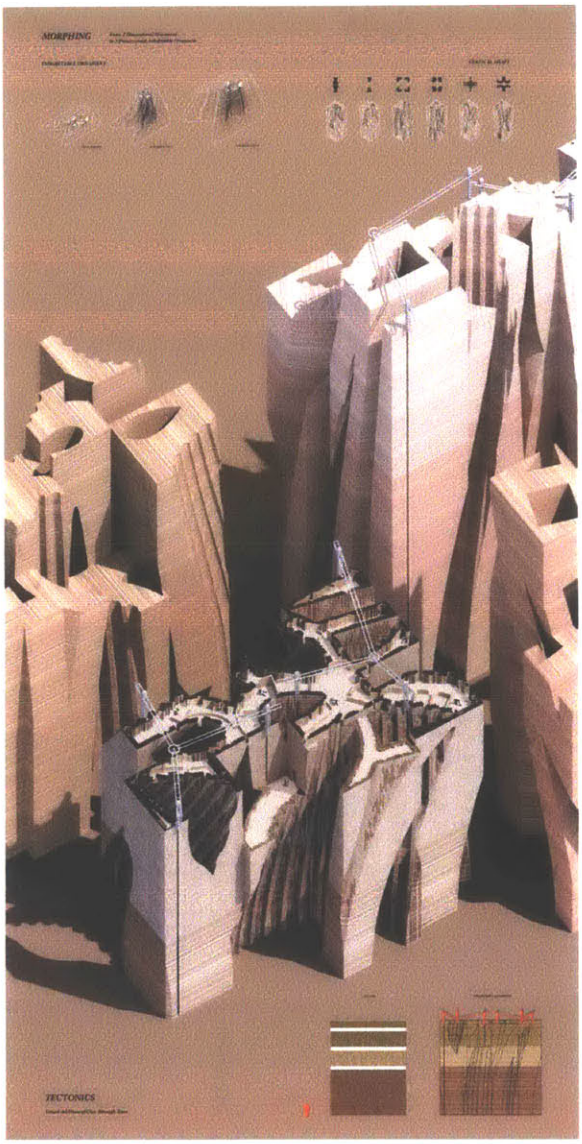
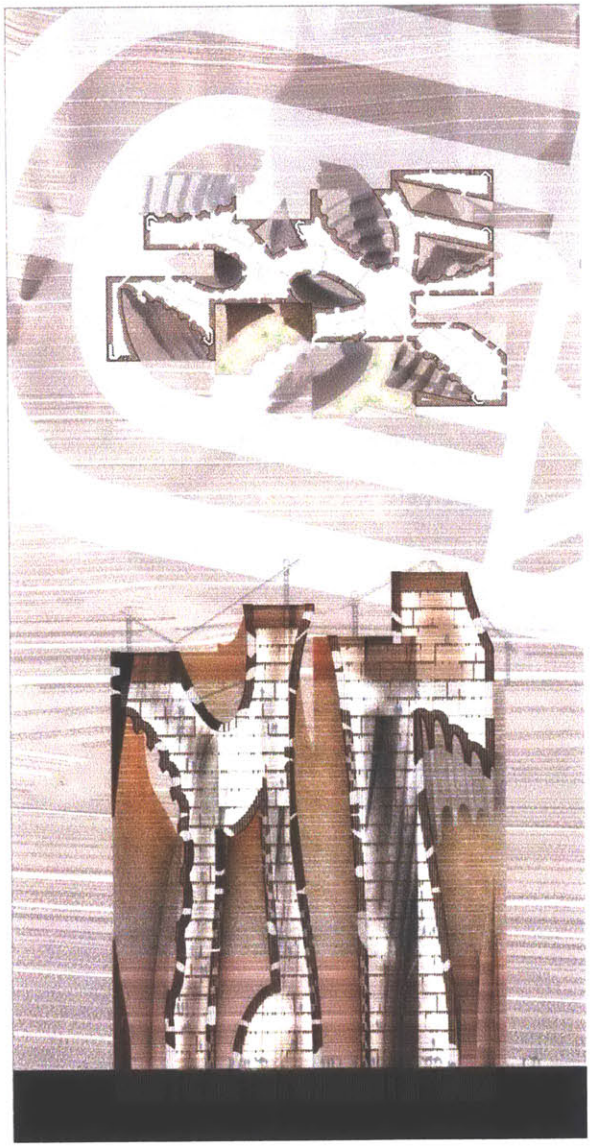
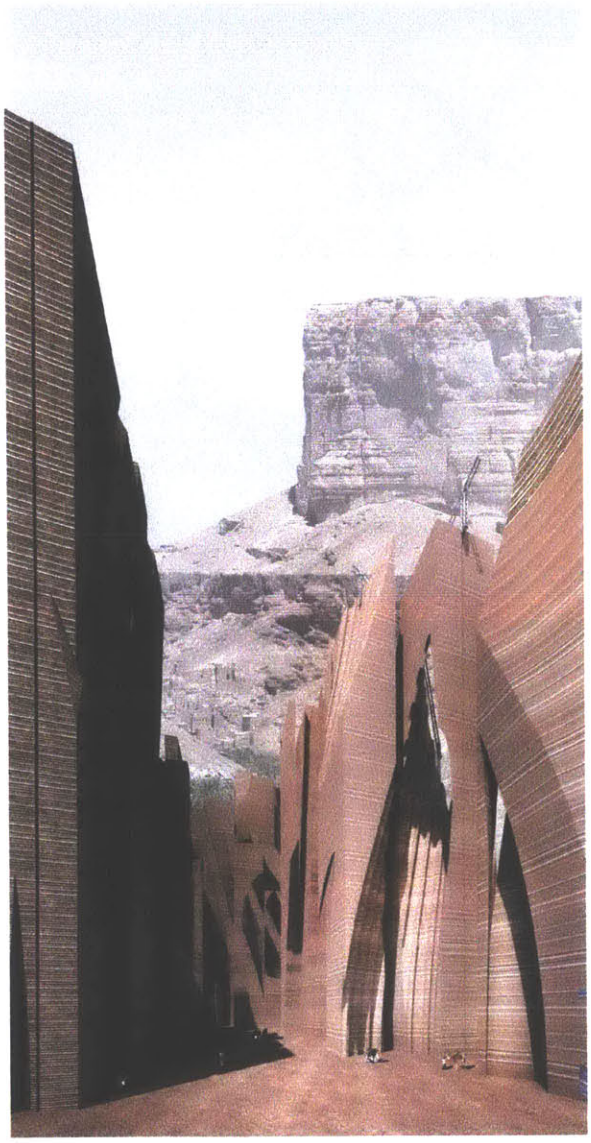
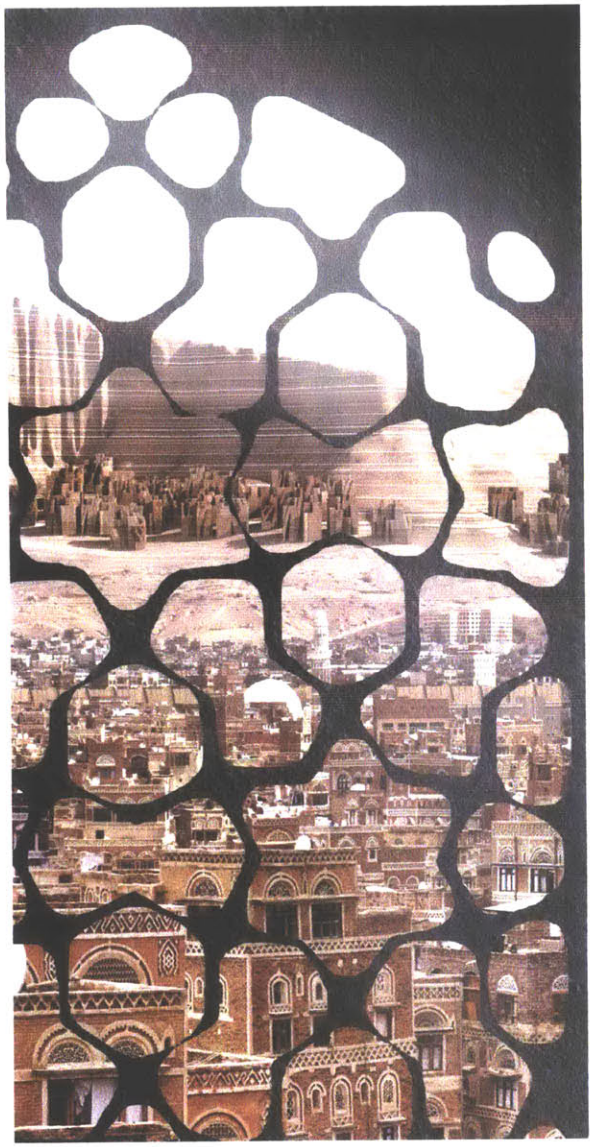
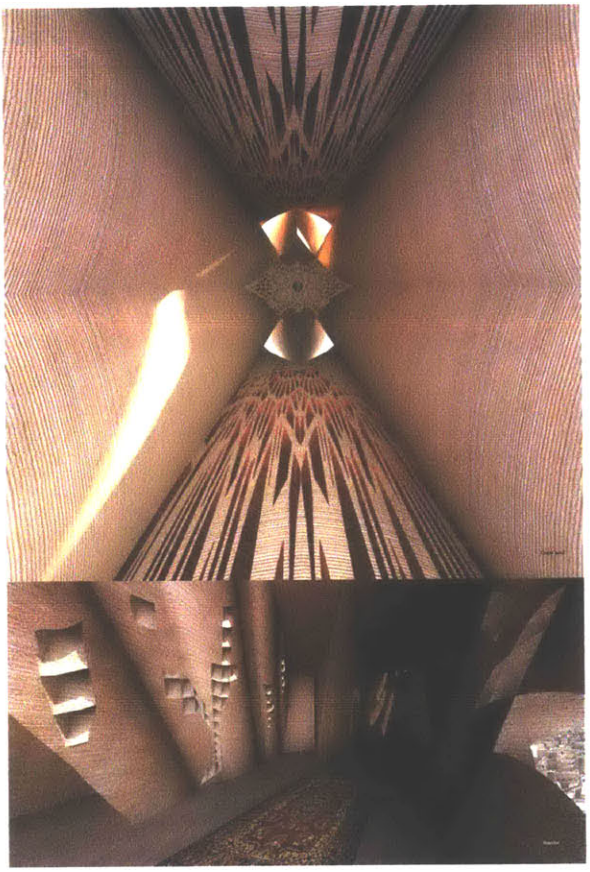
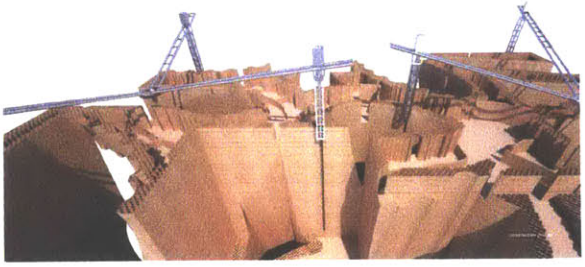

MORPHING
TECTONICS











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