Magnetic architecture
A NEW ORDER IN DESIGN

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ABSTRACT:
With the exploration of additive manufacturing, Magnetic Architecture develops different systems and strategies to use magnetic fields for controlling material through construction. In this research we utilize the overlapping of different technologies and digital tools that participate in the innovation of architecture. Thanks to hacked 6-axis robots, Magnetic Architecture approaches decision making from a top/down and bottom/up process. These new processes and conclusions are continuously leading to more areas of research and new design processes, which begins to question the role of the architect with these emerging technologies.

KEYWORDS:
Additive Manufacturing; Sensor Logic; Incremental Coding; Dynamic Blueprints (DBP)*
*Dynamic blueprints (DBP) - An approach in architectural design where a structure’s final design can not be determined until after construction. Designers no longer completely create the final form, instead dictate the fabrication behavior within the boundaries defined by the DBP.
INTRODUCTION TO MAGNETIC ARCHITECTURE

Magnetic Architecture is reformating the design approach to architecture in very specific ways. In no way is this a replacement, but a response to the emergence of robotics in architecture and how this changes our approach to construction. From design to production we have to consider how we are using these robots and why. It is not enough to simply combine new technologies and call it innovative. This research not only overlaps different disciplines but also strives to extract new vocabulary that begins to make sense of new robotic processes in architecture. There is reasoning behind these overlaps that brings a logical approach to using robotic control. When deciding to prioritize the importance of structural and material optimization, environmental considerations and use sensors to assist in the process of construction, the shift into architecture becomes more relevant. Magnetic Architecture cannot be architecture until these variables are precisely determined.

The DIY-open source culture is becoming more relevant and stronger in the architectural community and has assisted in pushing this research further. There is a sub-group of architects becoming coders / hackers. Not just using this design techniques as a plug-in, but completely understanding the mechanics and intelligence behind complex systems and geometries. Magnetic Architecture attempts to fit itself directly in this path. We are using sensors and new simulation techniques to communicate with magnetic material along with producing new configurations of positioning and controlling the magnetic fields themselves.

The current focus of Magnetic Architecture explores the design opportunities of a new building process from phase one: simply using recycled iron based material controlled within a magnetic field. With this technique the potential to increase the flexibility of the additive process to reach the architectural scale was visible. An attempt to combine all the decided considerations for design with this process lead to a goal in synching these considerations all within one design loop. This loop will allow the design process to be manipulated at any stage and reconfigure itself in order to provide logic to the robot that executes this design.

INTRODUCTION TO MAGNETIC FIELDS

An astronomer, physicist and philosopher by the name of William Gilbert (1540-1603) had become the strength in understanding magnetic fields back in the late 1500’s to early 1600’s. He wrote a book entitled De Magnete, which is the strength in the comprehension of magnetic fields. It was through understanding his techniques in his own research that Magnetic Architecture really gained momentum in our process of digitally controlling magnetic fields themselves. Michael Faraday’s representation on “lines of force”, which emerged almost one hundred years later, became crucial for bringing the invisible support structure of the magnetic field into three dimensional analysis. (see figure 1) The magnetic fields also communicates with another invisible force, gravity, that becomes important when understanding the positioning of these fields for construction use.
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"The first truly scientific study of magnetism was made by the Englishman William Gilbert (1540-1603), who published his classic book On the Magnet [De Magnete] in 1600. He experimented with lodestones and iron magnets, formed a clear picture of the Earth's magnetic field, and cleared away many superstitions that had clouded the subject. For more than a century and a half after Gilbert, no discoveries of any fundamental importance were made, although there were many practical improvements in the manufacture of magnets. Thus, in the eighteenth century, compound steel magnet were made, composed of many magnetized steel strips fastened together, which could lift 28 times their own weight of iron." (B. D. Cullity, C. D. Graham)

We took the intelligence of the magnetic field's capabilities to lift more weight than its own and understood this as a structural and architectural advantage of construction when entering into additive manufacturing research. Understanding the mathematical balance of the invisible forces of magnetic fields and gravity play a huge role in coding the pattern of field placement and became visible once iron was placed within the magnetic field. However, first we needed to understand and quantify how much of the raw material (iron) could be held with the magnets as seen in figure 2. Once we achieved our initial comprehension of the magnetic field and how iron reacted in the field and with gravity the decision to move into electromagnets from neodymium magnets, shown in figure 2, was clear. We wanted the maximum control over the magnetic field and electromagnets allowed us to have a digital control over the strength of the field, though neodymium magnets still proved useful when testing new iron based materials at this scale.

The Iron-based Material

The collection of iron began from approaching businesses who had this raw material as scrap. Locksmiths who after shaving down keys would be left with a pile of iron that would simply be thrown away, and they became a trade very useful in the collection of iron. Through many discussions of magnetic material, the most common natural form of iron, magnetite, was suggested by a colleague who informed us that magnetite could very well be in the mixture of sand located at our local beach. (see figure 3) The understanding that the core ingredient for making magnetic material possible could be from both a recycled and naturally collected process became an ecological goal to continue to adhere to. It was understood that any industry with scrap metal was of great use when approaching the scale of architecture (mainly auto shops and junk yards). The mapping of global magnetite existence raised the question, "Should Magnetic Architecture only exist where there is plenty of recycled iron and magnetite deposits?"
Now that we had a system of where and how to collect material, the question lied in how do we solidify the material in its place for the process of additive manufacturing. Jolan van der Wiel whose most noted for his “Gravity Stool” explains the use of a plastic resin mixed with an iron powder to create is sculptures that are formed with large and heavy magnets incorporated in a pulley system. Though his material is very impressive, we knew, could not be used at the architectural scale because his iron is manufactured into powder. We began with thirty-two different mixtures were we tested the strength of the final formation. Figure 3 is one of the strongest and most coherent mixtures for the use of architecture with this process. It consists of a natural resin, concrete, oil paint, and recycled iron. It was clear that there was a control and unique expression of this material and both qualities have their advantages.

In describing the Hot Networks Experiment 1, a robotic collaboration of stacking/piling of PETG plastic and fusing using heat and applied pressure, Brandon Kruysman and Jonathan Proto explain, “This allowed the objects to have a material and formal characteristics that range between control and wildness.” Magnetic Architecture is not only an artist expression of the control and freedom given to the natural formations with in the magnetic field but a scientific evolution in the use of magnetic fields, where the process of construction is now utilizing a method and an old scientific discovery that has never found it purpose here before. The development of material is a hefty investigation and may require the collaboration of material experts.

Programmatic Configuration

The first stage of the Magnetic Architectural design process is fairly simple. Starting from a programmatic diagrams, different spaces are positioned with their respective size. Each space is then attracted or repelled depending on their relation with the other and their relation with the context area depending on their programmatic link and circulation flow. At this stage, the spatial dimension and organization are defined without fixing the shape just defining the footprint of the structure. There is a given footprint, but these structures cannot be defined in contract documents until after construction. This is due to robotic construction having the ability to be programed to make decisions on its own that the designer can’t determine the exact formations.
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These initial decisions are traditional ones architects are very comfortable with. However, "Architecture continually informs and is informed by its models of representation and construction, perhaps never more so than now, when digital media and emerging technologies are rapidly expanding what we conceive to be formally, spatially and materially possible. Digital fabrication in particular, has spurred a design revolution, yielding a wealth of architectural invention and innovation." (pg. 4 Lisa Iwamoto)

It becomes evident that how architects use digital fabrication and material techniques to participate in the connection of the virtual and digital is key to our studies.

When merging robotics into the field of architecture new vocabulary will undoubtedly emerge. Trying to delimit the decision taken at local scale by the robot and the decision taken at global scale by the designer, we introduce the idea of Dynamic Blueprint (commonly called DBP). DBP is our first attempt into understanding the construction processes with robotic control and local decision. After integrating the programmatic and spatial definition in the DBP, the design can then shift into the next phase. Our design cycle still allows for reconfiguration at any stage of the process and we are constantly trying to develop a design loop that has no end until the designer says so.

Sensor Logic: Integrating the Material Consideration Deep in the Digital Fabrication

Challenging the traditional norms of linear file-to-factory production processes, we studied the potentials of linking the collection of material data with mechanic control. Implementing this information into a generative design gave way to new opportunities in approaching digital fabrication within architecture. We were not only collecting information from the magnetic material but we are developing a data model, open to the endless possibility of computational optimization.

The incorporation of sensors became very apparent when we saw that the formation of the material could never be duplicated. The material within the magnetic field was a unique formation every time, impossible to predict or precisely simulate. The material itself is a continuous investigation where the ingredients are exchangeable, however each mixture has slightly different effects when forming. Tokujin Yoshioka designed Venus Natural Crystal Chair that was formed from tiny crystals growing in an aquarium and this project was a great inspiration of letting our material express itself naturally. We took a more technological point of view in communicating with our material yet both remain as an artistic expression of designers controlling natural processes.

Our first sensor to include was artificial vision. In figure 5 we can see the initial formation generated from the constraints of the material and magnetic field being recorded through the lenses. This, however, is not the only reason for artificial vision. During construction regardless there is a use for depth sensors with infrared laser projector combined with a monochromatic CMOS sensor. Here during construction we can record and have a live upload of the actual material placement. We would be able to analyze the decision making of the system and autocorrect where needed, due to reading.
whether the formation just made was a healthy formation and if so where is the weakest part so the next formation can make up for it. (see figure 6) The collection of these formations live is not only deciding the next position but to ensure the top down density requirements for the entire structure are being met. In order to understand the reasoning for density variations we must understand how Magnetic Architecture approaches the structural and environmental filters.

Environmental Filter

In 2010 Sistema Consultores S.A. released an article about Autodesk® Ecotect™ explaining, “To migrate a building’s impact on the environment, it is important to first understand how the environment will impact the building.” With environmental analysis now being easily integrated into architectural design programs, designers can now consider - shadows, shading solar, lighting, thermal, ventilation and acoustics with complex geometries. Through the spatial reconfigurations that may happen later in the design phase this data can quickly be reformatted and make the incorporation of such considerations more comfortable and without third party collaboration. In figure 7 [1-3] that is exactly what is happening. On this hypothetical-exterior surface we are able to see how the sun effects the surface and determine the strength of light we want to come through the structure by varying the perforations that are directly linked to the sun analysis.

At this stage our environmental data currently consist of solar analysis to give us the next record of porosity perforations across the structure’s surface. This filter will communicate with the structural filter to ensure both considerations. Visually we provide a two dimensional array of color (on 3 channel RGB), one for the structural density and another for the permeability of the surface. These exist by inputting the spatially configured design into the specific site location. This form of analysis is an important tool for buildings responding to environmental conditions in order to establish some sustainable character. This can and could be applied to all architecture that strives for sustainability.

Structural Filter

The structural filter is divided into two processes. One is to define the global shape through a form finding algorithms. The second is defining the destiny of material with a topological optimization. (figure 7 [4-5]) Through form finding algorithms we can refine the position of the surface. Through an
iterative process including the spatial and programmatic consideration to the structure logic, the global shape of the surface is set. (figure 7 [6]) This material density acts as a bounding box for where the robot can incrementally configure the magnetic material with the electromagnets.

With the topological optimization on this surface it is possible to determine the area where more density of material (i.e. density of columns) is needed. The pattern developed in our previous research permits such flexibility that the robot will take this decision during the fabrication according to the scan of the formation from artificial vision. We end up with a DBP composed of a 3D surface (setting the axial line of the future walls) integrating the required density of material in a gradient of color. In figure 7 [6] we can a grey scale that, in code, contains a numerical percentage of material to be placed in that area. The robot will not continue until the percentage is obtained.

The Loop Overview

The loop is a design process of automatizing design decisions, structural optimization, environmental consideration with live incremental decision making. It is an attempt to fluidly link a top - down and bottom - up process through code for predetermined geometries and live decision making through construction. Lisa Iwamoto explains in her collection of projects entitled, Digital Fabrication: Architectural and Material Techniques, “Like traditional drawing, digital production is a generative medium that comes with its own host of restraints and possibilities. Digital practices have the potential to narrow the gap between representation and building, affording a hypothetically seamless connection between design and making. . . as with all tools of production, the very techniques that open these investigation have their own sets of constraints and gear particular ways of working.” Magnetic architecture is not only trying to open these techniques but close the gap in time for a cohesive conversation between designer and robot in the context of construction.

After the location of a project has been set both material and environmental studies can be performed. Because the material is based on location and access to recycled material and availability of natural material, the behavior of that material within the magnetic field varies from location to location. The rules for the robot are designed to abide by the final material mixture and these limitations are then written into the code. When finalizing the configuration and needs for the space, structural optimization can then kick in. This formation is given to the environmental filter and back to the designer to decide on the gradient of density throughout the entire structure. The design is fed back into
structural optimization to ensure its stability. All of this information is fed directly to the robot to act as a bounding box for where the robot can build. Through artificial vision we collect the exact amount of material and record the formations being placed to ensure the final design is responding to the bounding box given by the designers decision, structural outcome and environmental considerations.

Figure 10 - A model that was formed with neodymium magnets in Phase 2 were we explore the use of using a magnetic field configured with only one magnet.

This entire loop is currently theoretical but all tasks have been performed in their separate stages. One of the aims of Magnetic Architecture is to continue to synch these codes together in one program which could be used not only for our research but for the future of additive manufacturing when dealing with natural materials who have certain behaviors that need to be looked after during construction. Many researchers are developing new systems within this field and with the increase of bioengineering and materiality this loop becomes more clear in its direction.

Summary

It is uncertain where Magnetic Architecture will finalize its place in architecture but the exploration within this research has provided a great amount of information in using technologies for the purpose of architecture itself. These formation are still under investigation as far as balancing complete control over the material or allowing it to have some freedom where the fascination of these invisible forces is still exposed. The design of the tool (figure 11) shows a shield that protects the electromagnet from the material. It is the design of that shield which really dictates some of the necessary elements for architecture (even to obtain perfect right angles). This control is possible but has not yet been a priority.

Neri Oxman (2007) describe the “factory to file” protocols, “machine execution should not merely be regarded simply as a service tool for materializing design but rather an opportunity to inform the design process as one which integrates machine-logic across all scales of production. Material choice and fabrication methods are not innocent decisions, but are rather predetermined factors which guide the design both with respect to artifact and process from start to end.”

Magnetic Architecture is not just a platform to explore additive manufacturing but a study on new technologies emerging in architecture. These first steps in design can be applied to any design processes in architecture today for the technology is available and ready to be used. It is the mindset of the designer to consider these filters. With these new approaches architects are forced to become smarter designers. We are no longer just making pretty spaces and giving them to engineers to solve the complexities but we are in fact are the designers of these complex organizations. We are stretching into new fields and understanding that architecture essential can be the top industry to push innovation and become the connector of all technologies once again.
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