Digital Construction: An Integrated Digital Approach to Architectural Processes

Currently, there are three trends occurring in the architecture/construction industry which will have long-lasting implications on the way buildings are designed, fabricated and constructed.

The first of these trends deals with waste, where a large amount of waste is generated during the construction phase. Linking digital models to fabrication processes already has reduced the amount of waste during the early stages of construction. However, unlike fabrication, construction remains relatively far behind in terms of its reduction of waste.

Waste, it is synonymous with human culture and our attempts to create a sustainable future for civilization. But in the age of information, so too are concepts like networks, intelligent systems and big data identifiable with human civilization. What we currently lack in our efforts to achieve a sustainable human habitat, we are only beginning to touch upon with ideas like lifecycle building, integrated project delivery, building information modeling, digital fabrication and energy consumption analysis. Before the rise of the internet as we know it today, we lacked the ability to rapidly pull information from anywhere in the world and be able to visualize vast amounts of data to problems that were previously unknown to us, as we looked at only a subset of what was actually happening in a larger network of events.
Presently, we are talking about energy analysis on digital building models, post-construction energy analysis and building information modeling. What we lack, is a system that begins to have each of the components along the path of construction, the assimilation of matter from the time it leaves the ground until it is finally congealed into a structural form, speak to one another and be able to visualize across a larger field of study and the cause and effects relationship each has on the other. To be able to curb waste from our production cycle for building, we must be able to collect and visualize the necessary information along its path.

Matter-Data Network
To begin mitigating waste within the construction industry, we must look at the highest efficacy value – the highest being prevention. To date, the main conversations are surrounding topics of minimization, reuse and recycling, moving away from concepts of energy recovery and outright disposal. Prevention implies a “smart” system, a network that tracks material for construction from the moment it is pulled from the Earth, to its virtual manifestation and configuration inside of a digital model, the amalgamation of a built entity, to the re-use or recycling of its constituent parts after the structure has been decommissioned.

Bruce Sterling, a technology theorist and science fiction writer, refers to the neologism of the Spime, where unique and identifiable materials and goods are able to be tracked throughout their lifecycle, using such technologies as RFID tags. At any time, these materials’ geolocation and other tagged
information may be queried. This begins to build a database of known materials in the global production
cycle with the ability to track their movement throughout the cycle of production. For instance, within a
Building Information Model (BIM), items within the project’s digital model may be searched for, giving
their precise location either in route to the construction of the project or post-construction within the
building. This information is retained throughout the life of the product. The materials catalogued
become part of a larger repository of searchable physical objects in the world where we are able to keep
tabs on the amount of material within the production cycle and built environment.

**Production: Construction v. Manufacturing**
The second phase deals with the condition of productivity and efficiency. While the manufacturing
industry has continued to climb, mostly as a result of increased efficiencies in production due to
mechanization and computation, the construction industry has stagnated, flat-lined, and in some
circumstances, declined over time. As construction and labor costs continue to rise, people are looking
to the manufacturing industry for ways to cut costs in terms of labor and delivery of the product to their
clients.

Architectural fees continue to diminish under the weight of increased competition and greater building
costs, as firms continue to seek more efficient means of delivering the architectural product. This has led
many to skip the traditional use of sub-contractors, working directly with the fabricator and using the
building model directly for fabrication purposes, in an effort to save money, control quality and decrease
unnecessary steps of a middleman.
This is leading some to look at what has enabled the manufacturing industry to continue to efficiently increase production at an almost exponential rate – automation and robotics. Today, robots are used in manufacturing for material handling, processing operations, assembly and inspection. The adoption of robotics has made processes more efficient and productive over time. These processes can be directly related to the construction industry, as the applications are strikingly similar. Architects are frequently turning to a robotic workforce to fabricate more complex building facades that are directly tied to their digital models. Similarly, plans are on the horizon to make things such as vehicular shipping and driving more efficient and productive with algorithms, by determining the best routes for trucks to take. The military and Google are already utilizing such autonomous vehicles in their operations.

By automating and tracking vehicles (resources), processes such as these may be tied directly into a building model with the ability to instruct their movements and operations. As military research and technology trickles down to become consumer products, technologies like Unmanned Aerial Vehicles (UAVs) will become more prevalent. Combined with advanced cameras, accurate digital terrains may be modeled with the ability to tie directly into the digital model. The entire process of site operations becomes automated and tied directly to the digital model, where the UAV monitors the transformation of the site to create a repository and history of site operations in real time. Universities across the globe already are adopting technologies with the ability to automate fabrication processes; in most cases, researching the operations of multiple robots at any given time. As students become more familiar with these technologies and they are further implemented in education and fabrication stages, students will drive the future market for a proliferation of digital/robotic control.

With tools such as these, we are able to gain more precision between what is modeled and what is fabricated and constructed. The project titled “Wave Pavilion,” by graduate students at the University of Michigan, utilized one robotic arm to bend steel rods according to splines in a digital model. Another robot could be used to place in space and spot weld the sections together. What only took this team of robots and students a few days to fabricate and construct, would have taken weeks to accomplish given the complexity of the digital model. It becomes inefficient at that point to break the chain of automation, stopping at fabrication and returning to a manual labor workforce for construction purposes.
Matter Lifecycle Management
The evolution of labor in human society toward that of mechanical-autopoesis is perhaps nowhere less evolved than the construction industry. While manufacturing and fabrication industries have, in large part, already moved toward systems of automation, building construction is by and large a manual operation of human labor. As a greater portion of the architectural field is moving toward digital processes, it makes less sense to break the chain of these processes to be interpreted by a manual workforce reliant on the unknown expertise and interpretive skillset of local laborers. Currently, the means of building construction utilize methods which are falling behind digital capabilities and methods [or processes] displayed during the beginning and interstitial stages of architectural development, i.e., the digital modeling and fabrication stages. Already, we are seeing once human labor processes in the chain of production being handed over for mechanized processes – in terms of fabricated elements that were once reliant on the skill of craftsmen. Architects and designers can now send their complex digital models to a mechanized workforce to be crafted/fabricated rather than relying on the unknown skill of local laborers or craftsmen, with greater control over the process and precision.

The automotive industry is a prime example, as vehicles not only are assembled, fabricated and constructed by a robotic workforce, but create a vast information network through monitoring materials as they traverse the systems of production in a mostly automated environment. Like the automotive industry processes, not only fabrication but construction as well has transitioned toward robotic processes – where vehicles are digitally modeled, fabricated and constructed using computational
means. Similar to fabrication processes which utilize robots, adding construction to this chain of events driven by digital models, allows the designer to directly influence, instruct and automate the timing and overall chain of events from design to fabrication to construction. With the utilization of 4D BIM modeling, it is not a leap to imagine the construction industry moving design the same way fabrication is today, or using the processes which the automotive industry has already adopted. What the automotive industry has learned, in terms of precision and efficiency, the architectural industry can similarly seek to gain.

Aviation also has a similar chain of production, with complex digital files and simulation models that far exceed the nature of the typical architectural process. Now we are seeing aviation models that are not only monitored during the fabrication and construction phases, but have grown to include monitoring systems post-construction. This year, the large aviation manufacturer, Boeing, will no longer sell jet engines. Rather, they will lease them so that over time, they may continually monitor the performance of jet engines within a larger data-set as opposed to monitoring an individual engine – where little information can be gathered compared to the emergent information that will be seen from looking at the entire field of engines operating within the world. Their monitoring not only allows them to see, in real-time, the performance of their product/design, but how to better re-design future engines, where second-order problems might arise that were not previously witnessed. These precedents share aspirations that are currently on par with those of the architectural community.
This brings us to the third trend occurring in the architectural profession which is, perhaps, leading toward a digital construction process. BIM software packages may, in the future, have the ability to tie together the aforementioned concepts of material tracking and robotic fabrication with the aim of being more efficient in workflow. Tied together with energy modeling and simulation practices, we are able to insert more data and create a greater level of detail in our digital models. Like robotics for manufacturing, BIM is increasing productivity and efficiency in terms of labor (on the architectural side). However, our current BIM and BLM (Building Lifecycle Management) models only see a part of the project – it pulls them out of their global context of matter. It looks at building processes only in terms of when the building team starts and when the building is handed over to the project owner or operations management.

But, what about the processes before and after construction? How are these processes linked through time to build a database, a larger picture, of what is occurring and how the project relates in its local, regional and global context (the stream of matter-flows)? To properly utilize BIM and BLM, we need to increase the scope of what the building model does and can do – the amount of information it has access to and what information it is sharing. This includes material tracking, automation, fabrication, material delivery and simulation. Drawings and details in the model become not just representations to be interpreted by a laborer, but actual instructional code for robotic production acting in physical space. In other words, your model controls a fully automated workforce directly tied to real-world operations.

In Japan, we are seeing systems that are using automation in hi-rise construction. A rig outfitted with robotic armatures moves up each floor with the construction of the building, controlled remotely by off-site operators and the digital model instruction code. They are able to monitor the status of the building in real time and control its operations. This is likened more to our notions of manufacturing that that of our traditional industry.

Technological advancements in stereo-lithographic printing (3D printing) are increasing as more people have begun to adopt the technology. We are seeing systems such as D-Shape and Contour Crafting which are fully automating the construction process by 3D printing full-scale structures. This year, there are plans to 3D print three full-scale houses, each vying for the right to be called the first fully 3D-printed livable structure. Last year and this year, both American and European space agencies announced plans and partnerships with universities and architects to 3D print a full-scale structure on the moon as a base for astronauts.

Further into data collection and automation processes tied to BIM models, we see not only robotics playing a large role in changing how we think about design, but that of simulation and monitoring of building systems post-construction. These processes are being used to help shape the building in the design phase, call on appropriate building materials for the context and monitor buildings throughout their lifecycle. This operability will likely increase in scope to include simulation of climate data as well as that of actual machines on the construction site. Machinery already on site, such as cranes and trucks, will increase in scope to include unmanned aerial/ground vehicles and robotics. These all may be instructed by the BIM model (like 6-axis robotic arms), where they are initially simulated (for collision detection) within the modeling environment and then convert each operation and building detail into machine code to be carried out by a robotic workforce.
Digital Construction
What is being proposed here is a fully integrated digital model for the process of architectural construction. This includes both monitoring of materials from geological sequestration to conception as well as a model fully instructed by a digital file that leads an orchestration of events in the process of building. As in fabrication, this translates to the architectural drawing as no longer being merely a representation, but becomes actual instruction for a robotic workforce. This includes a host of robotic “species” performing operations such as site surveying via unmanned aerial vehicles (UAVs), fabrication machines (6-axis robotic arms), on-site and in-site materials delivery (cranes and autonomous ground vehicles [AGVs]), additive and subtractive construction (6-axis robotic arms), material placement and connection (cranes, robotic arms, aerial agent-based robots), site work operations (AGVs) and post-construction autonomous robotics (utilized for maintenance and monitoring operations). Monitoring building material and post-construction performance is also integrated. This allows materials to be monitored from the time they are pulled from the ground in their raw element form, to their placement in digital/physical space, to their recycling – tracking and displaying the movement of matter throughout its full lifecycle.

This digitally controlled process would key in on-site deliveries of materials, management of robotic cranes and arms on the site to place components onto the building and, perhaps, even control the 3D printing of concrete structures. The entire construction site would become an automated and carefully timed orchestration driven by the architect’s digital model. A large amount of the processes on the construction site today could be controlled with a greater influence put on the digital model and carried
out by a computer-controlled robotic workforce. As our digital models grow more complex, it will become inefficient to leave the chain of events broken from computationally driven models to manual labor. Buildings today, with the use of BIM, parametric modeling and digital fabrication, may include a multitude of customized components that are growing more complex and difficult for unskilled or even skilled workers to construct preceding fabrication (based on time of construction or complexity of the project [numbers of components and connections]). To aid in the precision and timing of these models, robotic/digital construction offers the ability to directly receive information from the digital model, fabricate and construct the buildings in perhaps a more efficient and precise manner.

When pursuing this research, questions that are blatantly obvious arise as to the technicalities of such a system as well as one of economics and ethics. Like Foxconn in China [who manufactures parts for Apple], who are gearing up to replace 1,000,000 workers with 1,000,000 robots, we must ask ourselves what happens when 1,000,000 robots displace 1,000,000 construction workers. What happens when these robotics begin to not only take the jobs nobody wants, but begin taking jobs that people may actually want. What does this mean for our economy? The building industry? What happens to the displaced workforce and how are jobs re-appropriated to work side-by-side in a robotic workforce.