Légumes Urbaines: Digital Modeling Transformations + Prototype Fabrication Based on the Egg Crate Construction Method

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Abstract: This study is divided in two areas. First, investigating the architectural, structural and possible program qualities of the egg crate. The fundamental exchange between the mathematical realm -in the form of digital modeling- and the material realm – in the form of material prototype fabrication and manufacturing- is the second goal. This paper also focuses on a basic design problem: how to produce a system of variable cavities and niches as opportunities for adjust to different programmatic needs as well as different terrain conditions based on the egg crate construction method. The egg crate was first used as a conventional aspect of masonry systems of construction, from wooden boats to building hulls. Simply put, it’s a matrix of horizontal and vertical structural elements (or parallel to the x and y axis). The findings were incorporated into the design of prototypes for small-scale urban furniture / installations, the “Légumes urbaines”.

Keywords: Egg crate; monocoque; digital modeling; prototype fabrication & manufacturing.

The egg crate

Structurally, it is close to the monocoque system. Monocoque, from Greek for single (mono) and French for shell (coque), is a construction technique that supports structural load by using an object’s external skin as opposed to using an internal frame or truss that is then covered with a non-load-bearing skin. Monocoque construction was first widely used in aircraft in the 1930s, with the predominant types of fuselage structures like the monocoque and the semimonocoque. Unibody, or unitary construction, is a related construction technique for automobiles and airplanes in which the body or aircraft wings are integrated into a single unit with the chassis rather than having a separate body-on-frame (Figure 1). Structural skin is another term for the same concept.

The “Légumes urbaines” other than having the ability to bear their own weight, could exploit the variable niches within them as pods that can host some kind of program. Meaning, incorporate diverse
elements that are usually found scattered within the city, such as a post box / a free press stand / a bench / a recycle bin / a notice board or a street light. These elements often create “visual noise” in cities, thus the “Légumes” could possibly minimize that effect, acting as a homogenous container. Nevertheless, the Légumes would have to have a strong visual impact based on their form and color in order to attract its patrons or even raise public interest on specific issues, like recycling.

**Precedents**

The diverse contemporary precedents, having scale from a small bookcase, to large cantilevered structures demonstrate both the formal and structural novelty of the egg crate.

Architects Jakob & MacFarlane materialized the Loewey bookshop in Paris in 2001. It is an interior project, with bookcases that extend throughout the store in an organic manner. It was digitally modeled and fabricated using horizontal and vertical laser cut MDF wood panels (Figure 2).

The assembly of these panels was done in a conventional way. The same technique was used for the design and fabrication of “étagère three” a Plexiglas bookcase for Sawaya & Moroni in 2003.

Much more elaborate, [C]space is the winning entry in the ‘AADRLTen’ Pavilion competition. It is an advanced technology concrete structure that was erected in Bedford Square, London. Digitally designed, this open-air pavilion is a composition of numerous flat concrete panels positioned and joined in a 3-dimensional array. The architects had to digitally design each of the panels which then where laser cut and joined with custom made steel parts (Figure 3). The structure was designed and developed by Alan Dempsey and Alvin Huang with Adams Kara Taylor and members of the AADRL.

Metropol Parasol is a large scale project designed by architect Jurgen H.Mayer. It is an elevated public plaza in Seville, Spain that is currently under construction. In the initial design, the organic shape of the plaza acts as a load bearing structure that ends up into two giant columns (Figure 4). Structural details and joinery have not being disclosed yet.
Intentions

Other than the formal ‘newness’, or the ambiance & atmosphere that this technique could create on an architectural level, the precedents illustrate that there is space for innovative structural solutions or programmatic differentiation / variation and diverse spatial conditions.

Having a first glance at the precedents, one could assume that the material that was used for each of these structures was up to a certain degree determined from the very beginning of the schematic design. Especially large scale projects like the “Metropol Parasol” would call for some kind of structural analysis, i.e. definition of the possible materials & member dimensions that could do the job for such a span. Even for the Loewey bookstore, one can assume that the architects had some idea of the material and thickness they would use in order to bear the load of a certain amount of books.

Therefore, I realised that designing an egg crate structure would mean investigating the connection between the possible number of members and material as well as material thickness.

In order to have a first look of the egg crate system and the possible joints between parts, I focused on how to digitally model a small scale generic Légume with a small number of half cut parts, like a stool or a chair. The next step would be to digitally fabricate mock ups of the digital model using 3D printing and laser cutting that would help clarifying issues like structural stability, joint assembly and overall form study.

Based on the input of this minimal scheme, designing a more complicated Légume, a small scale urban furniture that could act as a bench, a free press stand and a recycle bin, would be the next step.

Digital modeling of the egg crate

Form finding for the Légume was done using software like AutoCAD, 3ds Max, Sketch Up, Maya and Rhino. Software with simple interface such as Sketch Up can produce fairly simple geometries, mostly by extruding 2D surfaces that were imported from AutoCAD, using the push/pull command. Thus, it can be useful in order to design each of the vertical and horizontal flat parts, that will then be put together to form the Légume. Dimensions of each part can easily be changed, according to the programmatic needs. On the other hand, this procedure is limiting when it comes to the form of the whole structure. The same applies for 3ds Max as well.

Choosing to use the Maya software environment as well as Rhino was more liberating when it comes to overall form. Exact dimensions can be set both in Rhino and Maya.

The first attempt was to create a generic component, which could then be cloned and transformed several times according to structural demands in order to build the whole Légume (Figure 5). Transformations where made either by adding specific deformers, like the lattice deformer, or by intervening directly on the component’s CV’s. Further action had to be taken, like extracting curves from surfaces and re-lofting in order to create a part that could be a simple loft between four curves. One of the final iterations was an assembly of eleven horizontal and vertical parts. I chose to cut down the number of parts, as an effort to save material, and reduce the fabricated prototype’s weight. Thus, the final iteration was more like a 3D puzzle, an assembly of only 8 parts (Figure 6). One of the issues I came to notice
Prototype fabrication matters

Small scale mock ups of Légumes 1 & 2 where fabricated, using thermoplastic 3D printing (Figure 11). The print scale was 1:10, meaning that a 1:1 prototype would be made of 2cm thick MDF sheets. These study models were useful in order to test possible joints and mounting solutions on different terrain as well as other pragmatic issues, like stability, weight and visual impact.

Another issue I had to deal with was the material I would use in order to fabricate the physical model using laser cutting. So far, I had been digitally modeling using “thickened” surfaces, so one of the choices was to build a physical model out of something extremely thin, like balsa wood or extremely thin MDF sheets. I knew that such a material in the...
A scaled physical model would stand for MDF / aluminum or steel sheets in a scale 1:1 prototype, like the bookstore by Jakob and MacFarlane.

Finally, I used 1.2mm thick strips of wood, to build scale 1:5 mock ups. Thus, I could test the scenario of a prototype made of 6mm MDF or steel sheets (Figure 12).

Laser cutting allowed checking the following issues:

a. Problems in assembling the parts. Some of the parts of Legume2 had to be moved and rotated in the digital model in order to fit with the connecting parts. The physical model verified that these movements could be made in the real world (Figure 13).

b. Verification of load bearing ability. Using 6mm thin (real world) parts would probably call for a thicker array of horizontal and vertical members.

c. Checking the joints. Using 2cm thick MDF sheets could stand without extra joint support. Using 6mm steel sheets would need some welding.

**Generalization**

What seems to be particularly interesting regarding the egg crate construction method is the possibility of finding some assembly or joinery technique that could be applied to projects of different scale. Assembling half-cut vertical and horizontal members with specific thickness, could produce load bearing structures, from a stool, to more complicated projects like the Serpentine Pavilion by Alvaro Siza and Souto de Moura, built in Hyde Park, London in 2005 (Figure 14). Small scale structures like a stool can allow using parts that are laser cut as a single piece, whereas larger structures need further breaking down of the parts into shorter pieces, according to typical material / sheet sizes found in the building industry.

Another benefit of this system is the ability to fabricate mass and low-cost custom made parts for projects with sophisticated forms in a small time period, due to the prototype fabrication techniques, like laser cutting or CNC milling.
Depending on the scale of the project, such a building technique could be simplified and mapped out, like an IKEA piece of furniture, a 3D puzzle that can be assembled by following a series of specific steps. Laser cut parts and joints could be packed, shipped and then assembled virtually anywhere in the world.

Sheets of wood or any other material can be easily stacked one over the other, making transportation much easier.

**Assessment**

The first thing one can notice is that using a fewer amount of parts calls for thicker and wider parts when using wood. Basic material technology knowledge could let one assume that steel or aluminium members would be thinner for the same amount of parts. Economy of material would surely mean fewer numbers of parts. The egg crate system can easily become redundant or not economical when
it comes to the number of parts used, but that is an issue that can be of secondary importance when the primary goal is an iconic structure or some kind of ambiance.

The exchange between the mathematical realm / idea and physical three dimensional outputs by prototype fabrication & manufacturing was irreplaceable in order to understand and explore the possibilities of such an experiment. At the same time, the way light is diffused within the multiple parts of the model creates a certain ambiance.

One of the basic problems would be to design and fabricate the joints that would keep the vertical and horizontal paths in place, especially when
scaling up. The small sized mock ups were able to hold the parts in place just with cut out joints, whereas larger models would need a more sophisticated knot, like the one used for the [C]space at the ‘AADRLTen’ Pavilion. Beyond that, the spatial and structural conditions / transitions in such an aggregate structural system are innumerable.

A step further would be experimenting with parametric design / scripting in Rhino using the grasshopper plug-in to generate even more versions of the Légume, depending on different site parameters or different programmatic demands (Figure 15). Parametric design in this specific system could also address issues of minimum use of materials based on strength analysis and minimum component sizing.

The spatial and structural conditions / transitions in such an aggregate system are innumerable. I left for last something that might be just as - if
not more - important than all the issues discussed above. The first thing someone realizes by observing the physical model is the huge impact such a structure would have within the real world. Its form alone would surely raise discussions about the cultural context / significance and precedents of such an architectural gesture. Reminiscent of forms from gothic architecture, Gaudi’s architecture and artifacts, or even human bones, it would trigger discussions that move way beyond form, digital modeling or prototype fabrication, proving that architecture is highly connected to cultural production of an era.

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