An Open-Source Building System with Digitally Fabricated Components

A design- and production process that makes optimal use of the predicted next industrial revolution

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Abstract. *With digital fabrication, our hardware is starting to bear greater resemblance to software. This paper explores the potential of processes used in the development of open-source software for the field of Architecture. The developed design process is connected to a building system that provides new insights on constructing with CNC-cut 2D elements and friction fit connections. Underlying the design process and the building system is Master's thesis research work conducted at Delft University of Technology.*
Keywords. *Open-source; building system; digital fabrication; CNC; friction fit.*

THE NEXT INDUSTRIAL REVOLUTION

The influence of Computer Aided Design (CAD), which has rapidly grown throughout the past decades, is currently complemented by a growing influence of Computer Aided Manufacturing (CAM). Digital fabrication creates a direct link between our digital and physical worlds and has the potential to increase the performance of construction processes. Some experts in this field – like Gershenfeld (2007) and Anderson (2012) – predict a next industrial revolution that is not only about new ways of producing physical objects, but also about new ways of collaborating, sharing, marketing and financing. Where the first industrial revolution democratized consumption, the next one is expected to democratize production – through digital networks of shared knowledge and digital fabrication devices.

OPEN-SOURCE

The direct connection between atoms and bits, offered by digital fabrication, enables us to create buildings in the same way as we create open-source software. Digital, customizable blueprints of physical building parts could be shared and developed globally like pieces of source code for a script, before directly being constructed locally with digital fabrication devices.

Open-source architecture has great potential to improve quality and stimulate innovation in the vast majority of buildings currently created without architects. "By 2030, the population of the world living in cities will have increased from 3 to 5 billion, with 2 billion of these living below the poverty line. The problem the world needs to solve is to build a 1-million-inhabitant city per week for the next 20

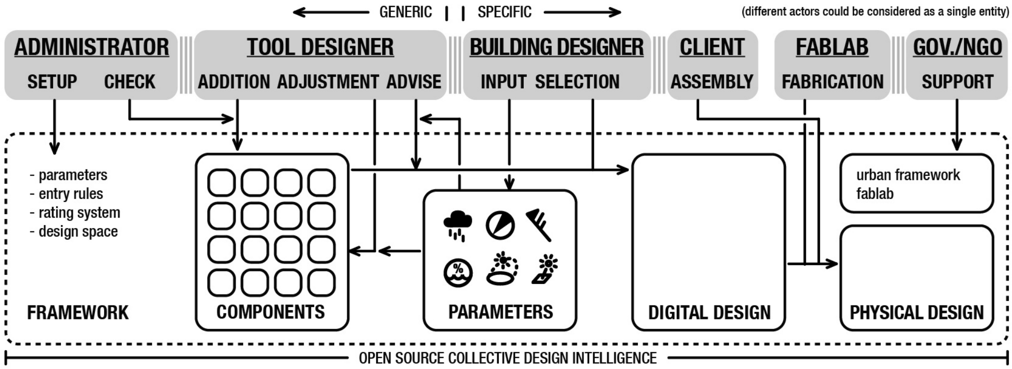


Figure 1
An open-source design process that facilitates evolution of collective design intelligence by splitting the design into a generic and a specific part.

years for $10,000 per family" (Aravena, 2011). Only by opening up design to collaboration in a structured way can we arm ourselves with the greatest knowledge and creativity available, required to take up challenges of such scale.

Recently, a great number of open-source hardware projects have been initiated successfully. In these initiatives, people with a broad variety in background, age and professional expertise collaborate online to develop and design a new physical object. Wikispeed, for example, clearly shows the potential of this innovative way of design and development; a great community developed an ultra-efficient 42km/l (109 MPG) sports car priced at a modest $25.000 in just three months [1] – an achievement traditional automotive industries cannot match up to.

In architecture the more advanced and interactive sharing tools are generally only used to share knowledge within single projects. Knowledge diffusion between different projects still happens in the classic form of non-interactive publications (printed or online). A few exceptions, like the Open Architecture Network [2], aim at digitally evolving a collective body of holistic design knowledge, but do not use the full potential offered by the digital and predicted next industrial revolution.

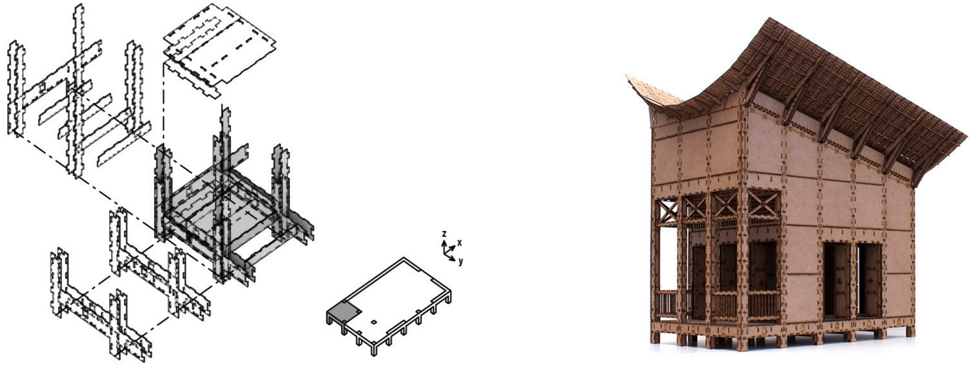
DESIGN PROCESS

In the design process proposed here (Figure 1), the classic role of the designer is split in that of the 'Tool Designer' and the 'Building Designer'. Both roles can still be fulfilled by the same person. The Tool Designer focusses on developing open-source collective design knowledge that can be shared globally and developed over time (this is the generic part of the design process). The Building Designer uses this knowledge to make highly specific designs that perfectly fit specific locations, climates, cultures and personal preferences (this is the specific part of the design process). Digital fabrication fully supports such mass customization.

The open-source collective design knowledge is structured in a database containing parametric blueprints of digitally fabricated building components. Parametric input not only adjusts the components to meet certain objective requirements (structural, thermal, acoustical etc.) but also generates specific advice for the Building Designer regarding less objective issues (spatial, social, cultural etc.). When designing in a cold climatic zone for example, the wall thickness could be automatically adjusted to meet insulation requirements, and the building designer could be advised to assemble the components in a compact volume to make the building lose less heat. The system of advice and adjustments helps the Building Designer to determine and balance both quantitative and qualitative performative aspects in an effective way, without limiting the designer's freedom.

Both the customizable blueprints of compo-

Figure 2
left: An exploded view of one of the components in the building system, including elements of structure and floor. right: A 1:10 scale model of a designed shelter for Haiti that provides optimal protection, electricity and clean drinking water.



nents and the effects of parametric input are part of the collective design knowledge. A system of database entry rules checked by administrators ensures overall quality. FabLabs and clients can play a key role in transforming the design directly from the digital to the physical world via digital fabrication.

In the design software, components are visualized as abstracted rasterized pictures; used by the Building Designer, and in full detailed vectors; used by the Tool Designer. This way, the design software for the Building Designer can also be understood by non-experienced designers and can run on simple platforms like mobile phones. As the entire design process is digital, the Building Designer can be provided with real-time relevant information regarding costs, environmental impact, required building time etc.

CASE STUDY PROJECT

The developed digital design process is tested and specified via a realistic case study related to the expected increase in demand for quickly realizable post-disaster housing for the mid-to long term. A transitional shelter is designed for Villa Rosa; an informal settlement south east of Port-Au-Prince, Haiti.

The specific advice and adjustments in the design process are merged in a concept that perfectly fits its climatic, cultural, technological and historical context. A concentrated solar power system integrated in the parabolic roof provides three basic needs: protection, electricity and clean drinking water. The ornamentation made possible by the building system demonstrates similarities with Haitian vernacular architecture of highly decorated gingerbread houses.

BUILDING SYSTEM

Just as there are different software code languages, the database of the proposed design process will be filled with blueprints of objects that can be physicalized with different digital fabrication techniques.

The building system developed here consists of CNC-cut 2D elements that are locally fabricated and assembled using integrated friction-fit connections, a construction principle explored earlier at Massachusetts Institute of Technology (Sass and Botha, 2006). This construction principle has great potential in the described case study and formed a starting point in the development of a new building system that is suitable for open-source development.

Three levels of scale - details, elements and components - can be compared to the words, lines and scripts, respectively, in open-source software code. The components are classified by three types: structure, floors and walls. Both level and classification ensure easy adaptability and extendibility of the building system while limiting its complexity (Figure 2).

The new building system is a combination between a balloon frame system and a column and beam system. This combination maximizes material efficiency while allowing the physical building to be easily altered in a later stage.

Advanced 2,5D milled friction fit connections make optimal use of the third axis on a standard CNC-router to minimize the degrees of freedom of each assembled element. Most joints are designed in such way that its pieces are secured in all three directions.

The details contain two types of tolerances; one based on variance in plate thickness due to factory differences and material expansion and one – much smaller –based on the accuracy of CNC machines.

To maximize the friction fit area between the elements, the floor- and wall components are related to a grid that is displaced a half grid size relative to the grid of the structure components. As a result, the whole structure is rigid.

Several principles have been developed to maximize material efficiency in the nesting process. The grid size of 1200mm is based on standard sheet sizes, as are the sizes of all elements. The floor tiles are divided such that they fit in the leftover spaces of cross-shaped beam-column elements. Elements like secondary beams are designed to fit together and share one tool path. Collectively, these principles reduce the total amount of waste as a result of nesting inefficiency to less than 10%.

CONCLUSIONS

The developed process uses digital technologies to allow broadly defined building performance to become the main guiding design principle. The system of adjustment and advice does more than merely optimizing quantitative parameters. Moreover, it fully supports the designer in creatively and effectively balancing the many - sometimes conflicting - performance related aspects. Both the building system itself and the intelligence behind the online information- and simulation driven design context have great potential to be developed open-source, similar to the development of open-source software or other open-source hardware projects.

The proven principle of CNC cut elements with integrated friction fit connections for full scale building has been developed to reach new levels of adaptability, simplicity, material efficiency, aesthetics and structural performance.

Compared to similar alternatives, the case study shelter designed with this process and system provides better performance in relation to climate control, cultural adaptation, building time and environmental impact - for a comparable price.

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[1] http://www.wikispeed.com

[2] http://www.openarchitecturenetwork.org