New value chains in construction

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Abstract

Value chain analysis are used to study the value process production of companies. For construction industry, several change agents are affecting the value chains used. In this article, we review the state of art in additive manufacturing methods and 3D measuring technology. We propose a new value chain for construction employing these technologies, and compare this to the current value chain of the construction industry. Emerging technologies may radically change the construction industry and the way consumers buy construction services. Disruptive technologies, digitalization and servitization will change the business models and value networks in construction.

Keywords: value chain, additive manufacturing, 3D measuring, augmented reality, digitalization
1. Introduction

Value chain is a model of the corporate value forming process, first introduced by prof. Michael Porter (1985) in his book “Competitive Advantage: Creating and Sustaining Superior Performance”. It has been applied for the last 30 years to understand and analyze industries, and has proved a useful mechanism for portraying the chained linkage of activities that exist within traditional industries, particularly manufacturing. It has also to a great extent framed our thinking about value and value creation.

Value chain analysis is a process where a firm identifies its primary and support activities that add value to its final product and then analyze these activities to reduce costs or increase differentiation. Value chain represents the internal activities a firm engages in when transforming inputs into outputs. In value chain, each step of the process in which an individual product is produced from source materials is described, and each of these nodes in the value chain causes an incremental increase in value. These nodes can be physical production steps, such as weaving cotton, or they can be intangible steps, e.g. associating the product with a brand. Up until the 1990’s a central component in value creation was the generation of economic benefit by the company for its shareholders. During the previous two decades, the production of customer value has become the core aspect in value creation. Methods from design and social sciences have been applied to branding and service development. The topic of intangible value creation has been approached from a multidisciplinary perspective, where value is produced by all actions of a company, and formed on individual, social and societal levels (Tikka and Gävert, 2014).

The concept of a value chain has assumed a dominant position in the strategic analysis of industries. However, the model is underpinned by a certain value creating logic and its application results in accordant strategic postures. As products and services now have become ever more dematerialized and the value is ever more created in networks and alliances, the value chain concept cannot any more properly uncover all sources of value. The focus of value creation and analyses has now shifted to value networks, meaning that value is co-created by a combination of players in the network. Adopting a network approach, organizations focus not on the company or the industry, but the value-creating system itself. In contrast to the value chain logic, these functions are performed simultaneous rather than sequentially, and mutual adjustments are required with respect to network scope, capacity and the technical properties of the concurrent services. A value network is a business analysis perspective that describes social and technical resources within and between businesses. The nodes in a value network represent people (or roles). The nodes are connected by interactions that represent tangible and intangible deliverables. These deliverables take the form of knowledge or other intangibles and/or financial value. Value networks exhibit interdependence and account for the overall worth of products and services (Poppard and Rylander 2006, Allee 2000, 2008, Santoni and Taglioni, 2015).
Beyond the value network approach, Porter has developed his value views further to shared value that means value creation not only to company and customers but to the whole society. He says that companies often remain trapped in an outdated, narrow approach to value creation. Focused on optimizing short-term financial performance, they overlook the greatest unmet needs in the market as well as broader influences on their long-term success. Companies too often ignore the depletion of natural resources vital to their businesses, the viability of suppliers, and the economic distress of the communities in which they produce and sell (Porter & Kramer, 2011).

Construction industry has also faced changes. From an industrial logistics business, it is transforming to a service business. After this transformation, a construction company is primarily a service provider, from the point of view of its clients. The era of technical specifications and minimization of costs is rapidly coming to an end.

Several possibilities exist for improving customer value creation in construction business. In addition to advances in brand definition and customer interaction these possibilities are driven by technological development. Virtual world, and game engine technology have been used in value creation in massive multiplayer online games and virtual worlds. Some of these have emphasized the role of defining the user’s persona via surrounding space and activity (Lehdonvirta et al., 2009). In this article, we first review the developments of 3D printing in construction and the state of latest 3D measuring techniques. After this, we outline new value chains and operating methods in the construction industry, based on these technologies. Finally, we compare the proposed value chains to current value chains in construction industry.

2. Current value chain in construction

For mapping the current value chain, we look at the supply chain in construction industry, as presented by Vrijhoef and Koskela (2000). Based on their observations of a typical construction supply chain (figure 2), we can map the according value chain for the same parties (figure 3).
3. Change agents

3.1 Additive manufacturing technologies

Additive manufacturing (AM) techniques were originally developed as prototyping methods for the manufacturing industry and product development, one particular application being the prototyping of injection moulded plastic components. Later on, they have become widely known as 3D printing methods, and have spread to several new application areas with the emergence of affordable machinery. At the same time, the technology of 3D printing has advanced and the selection of ‘printable’ materials has grown (Schubert et al, 2013). In the editorial for the Rapid Prototyping Journal, Campbell, Bourell and Gibson (2012) summarize the four benefits that are pursued with the adoption of AM technology: customization, improved functionality, reduction of total amount of parts and aesthetics. As an example of improved functionality, they list a number of features from aerospace industry that have been attained with AM: integrated mechanical functionality, reduction of required assembly features and internal features of components (e.g. cooling ducts).

3D printing techniques have also been forecasted to revolutionize the construction industry. Some research on this topic has already been made (Buswell et al, 2007), and some experimental projects carried out (3DRS, 2015). Lim et
al (2012) review three different AM processes capable of achieving 3D-printing with concrete-like material. The authors estimate the potential advantages of these techniques for construction, and come up with a list of properties: increased freedom of design, reduction in mould costs, and integrated functionality of individual components (e.g. ducts). AM methods may, in future, enable the cost efficient manufacturing of large, geometrically complex, unique components, from materials applicable to construction (e.g. concrete). This could largely change the way current buildings are designed using identical, geometrically relatively simple, concrete elements. 3D printing technology is highly relevant for the construction industry as it is directly linked to logistics, customization, virtual models and manufacturing.

### 3.2 3D measuring

One of the first consumerized 3D measuring methods were the depth cameras, such as Microsoft Kinect. Depth camera images can be turned into point clouds, and used in 3D reconstruction (Izadi et al, 2011). Typical issues in when using depth cameras are the low measuring range compared e.g. to laser scanning (Falie and Buzuloiu, 2008), and noise in the depth measurements resulting in a limited accuracy (Izadi et al, 2011). 3D scanning sensors based on depth camera technology have even been integrated to smart mobile devices (Google, 2015).

Laser scanning technology has also developed quite rapidly. One of the development directions being the miniaturization of measuring equipment, reduction of sensor price, and the increased ease of use of the measuring instruments. For example, mobile laser scanning (MLS) has reached a point where the entire MLS system can be easily carried by single person (Kukko et al, 2012), and today systems of few kg have been prototyped.

3D measuring can also be performed by using photogrammetry. As the computational capacity has increased, automation of image analysis and 3D reconstruction has become possible. Image based systems can be built even from very affordable components (Straub et al., 2015). Applications of these algorithms from consumer camera data sets have also been presented. The process of 3D reconstruction from unordered sets of images consists from firstly, the estimation of camera orientations (e.g. Snavely et at., 2006), and secondly, the dense 3D reconstruction from image pairs (e.g. Hirschmuller, 2008). Several different algorithms exist for fast but dense stereo vision. They have been compared in different contexts by by e.g. Sunyoto et al. (2004), or Ahmadabadian et al. (2013).

In addition, other sensor types can also be utilized. Rosser, Morley and Smith (2015) propose a solution where orientation sensors commonly found in current smart phones are used, together with the devices camera acting as a sight, to obtain a coarse outline of room footprint. These footprints are then utilized in processing together with the house footprint (obtained from survey data) to produce a coarse 2.5D building model. The interesting aspect is that this solution, based entirely on consumer hardware and commonly available data, was able to reach an accuracy of some tens of centimetres.

### 3.3 Augmented reality

Another technological development approaching construction industry is the use virtual reality (VR) and augmented reality (AR) in creating immersive visualizations of virtual environments. Several projects have already employed AR/VR technology in visualizing BIM models. Finally, the 3D printing technology is rapidly changing manufacturing, and enabling mass customization on a previously unprecedented level. The AR technology will be used both to visualize 3D models in their future installation site, and help guide the installation activities (Behzadar and Kamat, 2005). Consumer products enabling AR or VR have been released, or announced by several companies during the last year, including Samsung Gear VR, Oculus Rift, Sony Morpheus, Google Cardboard and HTC Vive.
3.4 Multi-sided platforms

Afore-mentioned value networks are becoming more and more dynamic due to the emergence of multi-sided platforms (MSPs) enabled by digitalisation. These platforms typically connect two or more sides of the market via online services, benefiting from network effects, i.e. the platform becomes the more attractive the more users and complementary service providers it attracts. Different from supply-chain platforms e.g. for mass customisation, these platforms act as a foundation upon which external innovators can develop their own complementary products, technologies, or services (Gawer and Cusumano, 2014). Well-known examples of MSPs disrupting traditional industries and their business models are a.o. Uber for taxi services, AirBnB for accommodation services, Amazon for retailing and Apple Pay for banking.

Such MSP operators thrive on data-driven customer understanding and customer experience, enabled by faster innovation capabilities and greater profits than industries in general. These ecosystem drivers provide a branded platform for leading customer experience, provide seamlessly third-party products and services and match customer needs with other service providers, extracting “rents” from the business transactions (Weill and Wörs, 2015).

These platforms also generate new end-user services hard to envision beforehand, enabled by open innovation ecosystem. Often the platform operators come outside of traditional industry players, with ecosystem business design and complete customer understanding, disrupting traditional production-oriented business models.

4. Future value chain

New knowledge is producing competence-based growth and breakthroughs in the emerging fields of our society; robotics, positioning, navigation, image based tracking, geospatial information technology, and big data analysis. The wide adaption of these applications has the potential to revolutionize the entire value chain of construction.

It is possible to combine the techniques of 3D measuring, such as terrestrial laser scanning (TLS), and 3D printing. By this, replicas of real world objects can be made (Virtanen et al, 2014). The combination of 3D printing and 3D measuring opens significant possibilities of mass customization in the construction industry. By using 3D measuring tools available in e.g. smartphone, an individual consumer produces a 3D data set of his/her apartment. The measured data is further processed, automatically or semi-automatically to produce a 3D model of the measured space. After this, the 3D-model is applied to design of components. For example, a space divider can be planned using pre-made parametric models, that are then semi-automatically adapted to each individual space, using the 3D-model as a reference for measurements. This design process is carried out by the consumer, in an online service. The designed components utilize the possibilities offered by AM. They can include the necessary mounting features, and their internal structure can be optimized to reduce material consumption and maximize strength. The components are then manufactured using numerically controlled (NC) machines, such as 3D printers. After delivery, the parts are then assembled onsite. As the components are made to measure, the installation time is minimized. This process is illustrated in figure 4.
The drafted value chain of the process is shown in figure 5. It has to be noted, that in some cases the “Online constructor” and the manufacturer can be the same stakeholder. In similar fashion, the transport and installation may also be performed by this central operator. When comparing the two value chains (figures 3 and 5), we can see that there are differences both in the beginning of the chain (direct and indirect suppliers), and the later parts (contractor, contractee and designers).

In the first parts, the current value chain in construction is based on suppliers manufacturing individual parts from a single material (e.g. tiles, sheets, beams) that are then used in manufacturing (e.g. furniture), or modified and installed on site (e.g. construction materials). As the manufacturing of these parts is a traditional industrial process, they are geometrically simple, and there is a large group of these manufacturers. Furthermore, for more complex entities, such as furniture elements, there are direct suppliers (manufacturing furniture) and indirect suppliers (manufacturing materials). Additive manufacturing enables the production of varying, geometrically complex components. As the manufacturing process is tool free, unlike e.g. casting methods, and is not based on manufacturing the object by
removing material from a starting piece, like e.g. milling, the geometrical variance of parts or complicated geometry does not increase production costs. Therefore, components of a varying shapes can be manufactured by the same manufacturer, without using a large amount of pre-made parts. In the minimum situation, the only indirect supplier is the producer of the printing material. From a large amount of manufacturers producing geometrically simple objects, and longer value chains, we go to a small amount of manufacturers manufacturing complicated objects in a short value chain.

From an economic point of view, we are moving from incremental increase of value in small steps (manufacturing materials and parts, manufacturing components, construction on site), to rapid increase of value in one jump (AM manufacturing of component). The operator controlling the AM manufacturing step has more control, in terms of scheduling and price determination. The amount of logistics, and items held in storage are reduced, resulting in lower amounts of resources being tied in the process. For the consumer, and designer, the amount of customizability is increased. Less compromises have to made, to fit the design to offerings of manufacturers and available components.

In the last parts of the value chain, the “Online constructor” becomes a central stakeholder. For smaller operations, such as furniture installations, the roles of designer, manufacturer and contractor may merge into one. This is enabled by the consumer providing the digital 3D data of the site, the use of 3D Internet technologies for allowing the customer to make some design decisions, and the use of AM manufacturing methods to produce more complex components, requiring less work on site. The amount of stakeholders is reduced, resulting is less communication and procurement steps. The consumer buys a completed installation, operates jointly as the designer with the “online constructor”, after which the constructor acquires the components made with AM methods.

5. Discussion

Analysis of future value chains in the construction industry is a subject to large uncertainties. Making predictions based on technical development only is not sufficient, as the construction industry is also affected by e.g. regulation that may change. In addition, the large commercial operators in the field have an influence over the whole system. Finally, it is unrealistic to assume that single value chain could serve all situations encountered in construction industry. The supply chain presented in figure 3 is originally drafted for development of new projects. Retrofitting a single apartment and construction of a new residential area are inherently projects of different scale and different producer-customer relationship. The technological development is affecting both small and large scale construction projects, but the resulting value chain configuration may be different. The value chain presented in this article is clearly more oriented towards renovation operations than construction of new buildings, which was the focus of Vrijhoef and Koskela (2000).

Nevertheless the current value chains in construction are indeed changing. The rise of new procurement methods is changing the attitude towards building life cycle. For individual consumers, more simplified options are offered for detached housing (e.g. Boklok, 2015). By integrating aspects like fixed furniture installation into the package offered for the consumer, and reducing the amount of choice the customer has over the final product, the manufacturing of housing units can be made more efficient. Customization aspect is entirely missing from this approach, but otherwise the trend towards reducing the stakeholders a consumer has to communicate with, is present. In kitchen furniture business, the same trend is present in turn-key delivery services offered, that combine the planning, manufacturing and installation services under a single brand (e.g. Puustelli, 2015).

Technology enabled change is also present in current construction. For kitchens, some retailers offer online 3D plans, made by their own design services (K-Rauta, 2015). The role of a professional designer is still maintained, but 3D Internet becomes the medium of communication between the client and the retailer. The tools empowering an
individual consumer for interior design tasks are already emerging in software market (Planner 5D, 2015) and it is a matter of time before these become integrated to actual purchasing and manufacturing activities.

6. Conclusions

Additive manufacturing techniques suited for construction are beginning to emerge as commercialized tools. Three dimensional (3D) measuring can be performed by laser scanning, scanners utilizing triangulation principle, or by using photogrammetry. As these technologies have developed, the 3D measuring is increasingly available for consumers. By studying the current state and development direction of technology, we can attempt to forecast the possible value chains of future construction, and estimate their impact on the industry.

By combining 3D measuring, 3D printing, AR, VR and sensor technology the entire chain from planning, measuring to manufacturing and delivery can be digitalized, covering the entire life cycle of the built environment. In future construction, the user measures the to-be-altered environment with a mobile device, thus producing a digital model to be used in planning. In the planning phase new installation, a fixed furniture for example, is assembled from a set of pre-designed modules and individually made 3D printed components. Design, visualization, cost estimation and logistics planning are performed with online systems. After the order is places, the pieces are manufactured, delivered and finally installed. Digitalisation will change the business models towards data-driven, multisided platforms where value-added services and servitization will change the current constellations of value networks.

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