PRODUCT CONFIGURATION OF ROUNDABOUTS

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ABSTRACT

Many researchers claim that early design phases becomes crucial when creating buildable product models and that there is a need for connecting design and production constraints. Currently, this link is weak within infrastructure projects which results in cost overruns due to additional costs of late design. An important infrastructure product is roundabouts and the purpose of this study is to develop methods in the design of roundabouts that can be used in early conceptual phases of infrastructural projects, to avoid erroneous solutions transmitting downstream the value chain. To overcome this limitation a roundabout configurator was developed and validated in a single case study of the infrastructure project Gustavsbergs Allé, by adapting theory and principals from mass customization and design configuration. The configurator were made in SolidWorks and parametrically coupled with the use of Tacton Studio. The configurator generates a drawing and a protocol that informs the user of the chosen configuration and where it doesn't conform to the Swedish standards.

Our findings shows that it is possible to use theories from mass customization to develop configurators that improves the quality of a design in early phase, which is achieved by the automated evaluation of design requirements according to norms and standards. In the search for increased efficiency within infrastructural projects, parametric modeling configurators can be used to speed up the design process and expand the range of alternatives that can be generated. In that sense, this study contributes to the understanding of how mass customization principles in general can be used in construction and how it can be implemented in the design of specific projects.

Keywords: product platforms, configuration system, roundabouts

1. INTRODUCTION

Like many other areas in the construction industry, the infrastructure sector is blamed of having low productivity and innovation compared to the manufacturing industry (Teichholz, 2001). Today, the sector is in a situation where few variants are tested where engineering consultancies are forced to lowering their profit margins due to higher costs and insufficient reuse of solutions. It is also often debated by researchers and construction management that early stages of projects, i.e. design stages, is important in order to operate and manage projects during construction properly (Gerth et. al., 2013). Early stages relinquishes documents with uncertainties about regulatory compliance, resulting in lower quality of the final product with risks of accidents as an result. It is said that a substantial part of waste and failure can be related to errors and mistakes in the traditional on-off engineer-to-order product design process (Lopez and Love, 2012). Also the link to production constraints are neglected and as a result the design solutions are often not adapted for construction, which leads to a poor constructability of the product.

The present infrastructure process is divided into three phases: traffic analysis, design phase and the technical finalization (VGU, 2012). The traffic analysis aims to determine the functional requirements for the product. The design phase the aims to propose and lock a selected solution according to these requirements. Within this phase it is possible to create solutions without taking any constructability issues into account. This often leads to major revisions, where solutions made in early phases are completely re-drawn in the technical design phase to ensure quality of the final product.

One way of realizing better connection between design and production is to develop platforms from which a stream of derivative product and processes can be configured (Meyer and Lehnerd, 1997). Such a platform and configurator should be developed on the basis of modules to fit customers' needs of the target market segment (Hvam et. al., 2008). According to Erixon (1998), Modularization is described as "decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons". As seen in the definition the focus on interfaces and the development of the technical solutions in close relation to the company business goals, is an essential part of the modularization work. It also complies with the definition by Ulrich (1995), which describes a module as a "chunk", "A collection of components that implement the functions of the product". In order to establish modularization work in the construction industry it is necessary to define "the products in the product" to be able to reuse the methods that might increase the productivity and designing these solutions specific for the companies.

Several road design software are used today, usually having built-in support for roundabouts and are usually developed to support phase 3 where the technical design is done. But since (in many cases) the design phase has resulted in something that is not going to be built on, these tools can't be fully utilized. The large vendors has also not yet adapted these support-tools into the Swedish norm. By focusing on design support in early stages, an increase in productivity in the design and production could be achieved. As a result, solutions that are drawn in the design phase could be utilized in the technical stage of the design phase without major revisions.

Configurators are important in this process to control the design in the early stages and improve quality of the final product by ensuring that the rules are followed, but also by allowing more variations to be evaluated. They can also increase constructability through the coupling of standardized components e.g. standard curbs etc. The aim of this paper is therefor to describe the development of a configurator that can be used in early phases of the design process enabling constructability of products further downstream the value chain. The configurator developed and described in this paper thus works as an carrier of the product platform and enabler of mass customization principals in an consultancy firm in construction.

2. THEORY OF MASS CUSTOMIZATION

Tseng and Jiao (2001) defines mass customization as "producing goods and services to meet individual customers' needs with near mass production efficiency" balancing operational benefits of economy of scale with product variety and time-to-market to fulfill market needs. In the search for fulfilling these benefits definitions like product platform and configuration systems have been introduced (Piller, 2004).

2.1 Product platform

The product architecture is described as the arrangement and mapping of functional elements to physical components and the interfaces with other interacting physical components (Ulrich, 1995). A modular architecture has a one-to-one mapping between the functional element and the physical component of the product which provides the function with de-coupled interfaces between components (Kim and Suh, 1991; Ulrich, 1995). An integral architecture on the other hand includes a more complex mapping between functional elements, physical components and interfaces between components and is more often found in one-of-a-kind produced products (Ulrich, 1995).

A product family is a group of products with similar properties that can be derived from a common platform. Meyer and Lehnerd (1997) define a product platform as "A set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced". Harlou (2006) quote VW; "The platform is an entity that has no impact on the vehicle's outer skin" meaning that things customer cannot see, do not need to be unique and can thus be made standardized. The reason for developing product platforms is the search for increased variety for customer while retaining as little variety between products as possible, this while sustaining economies of scale (Jiao et. al., 2007).

A product portfolio can be seen as all possible products that a company can offer based on their product platform. Based on the company's product portfolio derived product families that addresses specific niche markets can be developed (Jiao et. al., 2007). De Weck et. al. (2003) means that to be able to target specific niche markets, the degree of commonality can't be too high, "each variant from product platform might not be competitive in its specific market segment due to inferior performance caused by sharing constraints". The key is therefor to develop products generated from a product platform focusing on the right criteria's from which a number of products can be derived either by adding, removing, or substituting one or more modules to the platform or by scaling the platform in one or more dimensions (Farrell and Simpson, 2003).

2.2 Configuration systems

Product configuration as described by Hvam et al. (2008) is an effective way of structuring products composed of standard parts, and product configuration is also a method of presenting products to customers. The concept of a configuration system is also known as constraint-based programming, where the solution space is defined and can be illustrated by a set of rules determining how components and modules can be combined into products. To be able to address the different stakeholders and disciplines, the product can be defined in product views showing relevant information for a specific actor. The product views with their related product structures can be defined according to Hvam et al. (2008) as; Customer, Engineering and Production view, where the flow and exchange of information from design to production and between stakeholders is believed to be important in order to improve the construction process. Traditional design is transformed into a configuration process supported by knowledge based engineering (KBE) of the final product, (Sandberg et al., 2008; Erixon, 1998). Additionally, products structured in a product model (platforms) become a company view of the product range that can be held in common by sales, design and production departments and carriers of knowledge.

Today there are manly four CAD applications to be used in infrastructure projects in Sweden that have configuration support; Via Novapoint, Autotrack, Civil 3D and Microstation. Via Novapoint and Autotrack is a plug-in software for Autocad whereas Via Novapoint was one of the first to be used for infrastructure projects in Sweden. Civil 3D is one of the most common CAD-programs in Sweden but only with French and US-standard built in by default. They all have in common that they have direct integrated support in the CAD-programs whereas the feedback loop can be relatively long since they can't be altered by the consult company that are using it and when norms are changed this might not be alter directly, making it hard to fulfill Erixons (1998) module driver; "Driven by company-specific reasons".

2.3 Information exchange

The flow and exchange of information from design to production and between stakeholders is believed to be important in order to improve the construction process. Currently there are no standardized exchange format for roundabouts. The lack of exchange format makes it hard to transfer a roundabout design from one application to another. The vision of storing and sharing information with the use of databases using a common data format like IFC is still not used in practice when jurisdiction in the industry complicates the use of shared models. Also, the implementation of the IFC schema in many commercial applications has been shown to be unreliable with information losses and distortions as a result (Pazlar and Turk, 2008). Instead, in current practice CAD formats like DWG or DGN is used. Often the information exchange between applications relies on propriety data formats, application specific exchange protocols or add-on solutions, (Racz, and Olofsson, 2009) Many of the application specific solutions are based on XML (eXtensible Markup Language) as the transport mechanism for exchange (Zhinling et. al., 2004). However, the structure of the information representing the roundabout is strongly related to the application used. This creates limitations, since roundabout applications fail to interpreter the roundabout data from another tool. Instead, information exchange between two tools is dependent on manually extraction, transfer and re-structure of information to fit the new environment, this can happened several times in a roundabout exchange process since it normally involves several of road designer and actors which is spread out in a long time horizon.

3. RESEARCH DESIGN

The research design is based on a single case study. The method was selected because case studies are suitable when studying complex processes in general (Yin,1994). Furthermore, within the case we used an action research methodology applied to a system development research (Nunamaker and Chen, 1990; Chiasson and Dexter, 2001). The aim with system development process was to show that it is possible to a practical use and implementation of a roundabout configurator within a large consultancy firm in Sweden. Following steps were carried out in the system development process:

- **Examine design requirements**: the purpose was to understand the design requirements of roundabouts in Sweden, and also to examine types of roundabout designed in Sweden. Within this work VGU (2012) was essential since it includes geometrical rules, parameters and recommendations. The content was prepared to be input to configurator in this step.
- **Economic feasibility study:** the study aimed to investigate if a roundabout configurator was feasible. Data collection consisted of in-depth interviews with experts and a survey to roundabout designers within the firm.
- **Build a prototype**: based on the outcomes step 1 and 2 a prototype configurator was developed. Norms from VGU was here mathematical expressed using different parametric expressions. Solidworks was selected together with the plugin Tactonworks in order to support this process. The package was selected due to its ability to create dynamic configurators that can be shared with many employees in the firm.
- **Validation**: was done by comparing the results from the demand feasibility study with the build prototype phase. By comparing the time estimated for creation of a roundabout with time spend using conventional methods. Furthermore, the output file from the configurator was compared with the results of a newly design project in order to ensure equal quality regarding geometrical properties.

The steps have been carried out in several of iterations by the main authors during a 2 year period.

4. DEVELOPMENT OF “PRODUCTS IN PRODUCTS”

4.1 Product platform

As described earlier, the product platform defines the subsystems and interfaces from which a stream of derivative products efficiently can be developed and produced for the fulfillment of customer needs. The product “road network” can be divided into different subsystems to find families of modules that can be developed separately and connected to the final assembly (product), see figure 1. The different modules needs to fulfill an specific function i.e. where it is preferable to use a roundabout or an normal junction. When these functions have been defined there is only a question of defining the interfaces between the identified modules that will not change over time. Much of this information are specified in norms and national regulation such as VGU (2012) and can be incorporated as parametric constraints in a design configurator. The regulations are general constraints that have to be imposed on the design and do not differentiate one company solution from another. However, other specific solutions such as having the right kinds of curbs, improving the constructability of the product, etc. can be implemented in the platform and configurators for improving the competitiveness , (Erixon, 1998).

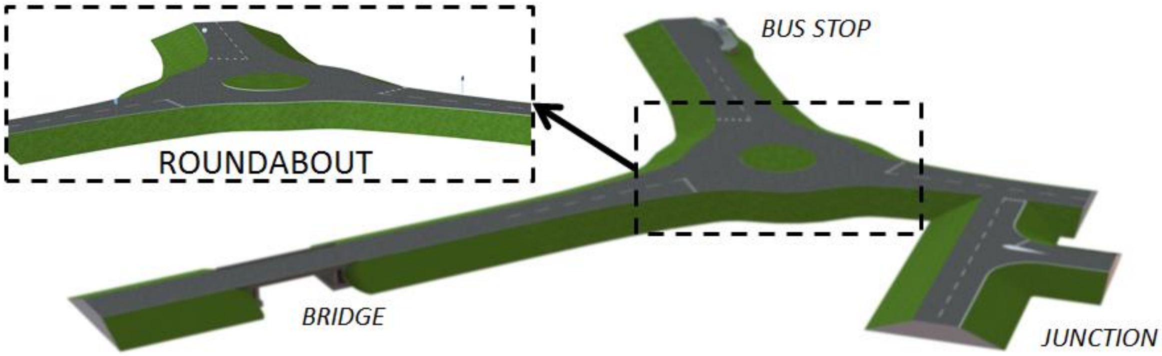

Figure 1: Decomposition of a road network and the module roundabout.

There are five variants of intersections in the Swedish road network, whereas variant D affects roundabouts. In the module family named roundabout there are thereafter four variants and an combination of these four. There are also roundabouts that can't be sorted in these family of variants and are therefore unique.

The functional requirements when roundabouts are suitable to use can be described as an proportion of flows to the intersection i.e. where secondary consideration is the proportion of 25-30% of the traffic flow or where the situation appears so that the circulation characteristics of the site is beneficial (VGU, 2012). Roundabouts constitute restrictions on the accessibility of primary road but affects accessibility on the secondary path positively. The effect on traffic flow is less than second tract proportion will be greater. At 50% reached an optimal ratio.

4.2 Configurator

The roundabout model to be connected to the configurator is built in SolidWorks (SW) which is a 3D CAD application designed especially for manufacturing. The program enables parameterization and has built-in features that tells you when the designer has fully defined its model. The program's functional structure consists of "Sketch", "Parts", and "Assemblies" and acts as a hierarchy where sketches are 2D drawings for the parts and then joined with several parts in an "Assembly" model. The software used to configure the SW-model is named Tacton Studio. Tacton Studio is a plug-in software that connects to SW rules to the measurements and dimensions that were created in the SW model so that it is configurable. Attribute linking configurator with the measurements and dimensions that were created in the SW model. The link attributes may control subsystem functions i.e. how wide, tall, long a measure should be. Each attribute is controlled by a Domain. The domain determines the limits within which attribute shall be permitted to be controlled. Constraints are the rules created in Tacton Studio and together with domain control limits within which attribute should act. Constraints can unlike domains used to change state in attributes. In this configurator constraints is used to keep the attributes within the framework VGU (2012) set for roundabouts. To be able to control the configurator there is a part of the program named User Interface (UI). UI offers opportunities to select the order of the attributes you want to control and if the attributes should be controlled by the input values or tables. Input questions can be hidden with "visibility attribute" so that the correct list is used in various choices such as, speed and number of lanes. Figure 2 describes some possible choices presented on the web that is used by the engineers at the consultancy firm.

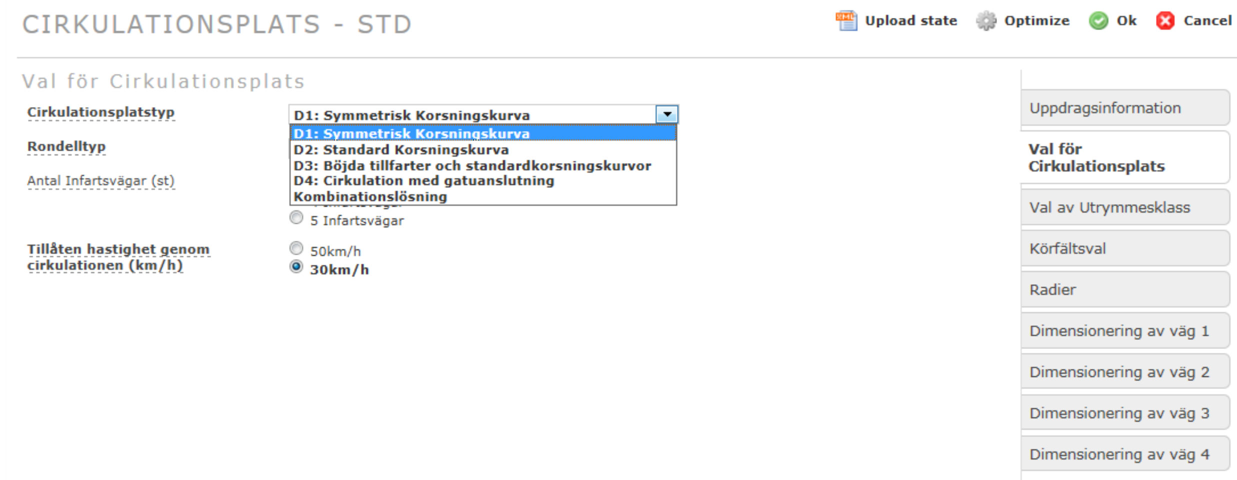

Figure 2: Screenshot of the configurator at the internal website.

4.3 Generation of drawings

The following section describes how the configurator can be linked to the current design process and help to ensure that more variants can be tested and secured before the detailed design can begin. Broadly drawn from the work of selected functional requirements for specific intersection is entered in the configurator where a solution is generated. The engineer designing the roundabout in the design phase can test and generate different solutions and present them to the client. Geometrical data is entered into the web interface described in figure 2, and then an alternative roundabout is generated with a protocol that informs the engineer where the norm has not been fulfilled. The output can then be imported to AutoCAD or used as an overlay for an hand drawn illustration. Once the client has approved the detailed design solution the technical phase can begin where Civil 3D is normally used and where surfaces and banks can be added. In figure 3 the design process for the design phase is shown.

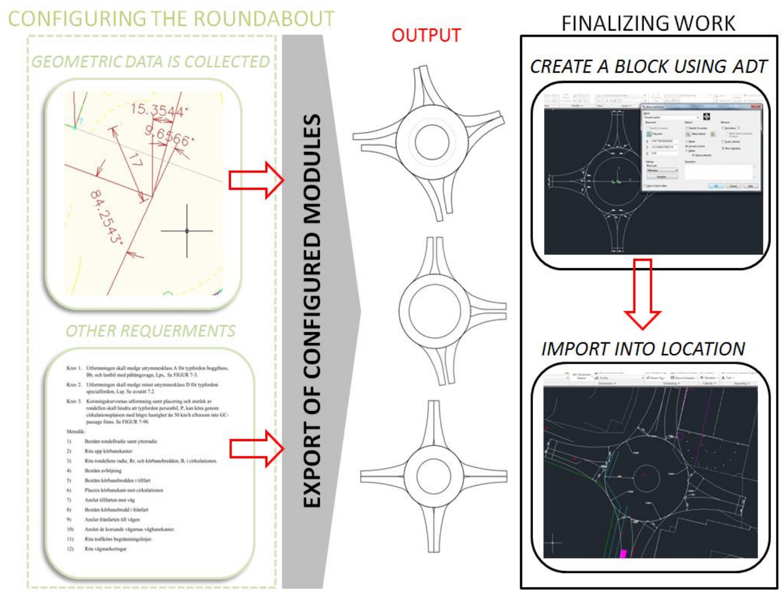

Figure 3: Use of configurator on the internal website and finalizing work.

4.4 Exchange of information

Civil 3D is the proposed application for detailed design of the roundabout. Civil 3D includes a wizard for roundabouts, users can in this environment specify values and other options for the circulatory road, approach roads, islands, road marks and traffic signs. It is possible to exchange information from the configurator as an XML which can be loaded into the wizard to changes these values. This saves time and secure the accuracy of the results and can also be connected with a template. Furthermore, another option is to use a plug-in e.g. Torus or Advance Power Roads which may have the possibilities to support creation of a roundabout with geometrical design and its attribute that was created from the configurator.

5. VALIDATION A DEVELOPED CONFIGURATOR IN AN REAL PROJECT

5.1 Description of the validation project

In 2012 Tyréns acquired an infrastructure project with a goal to redevelop a system of roads in Gustavsberg outside of Stockholm. The goal was to reduce the dense traffic on the main road – Gustavsbergs Allé and to expand its capacity to allow fan increase in commuter traffic. To both reduce the density and to increase capacity at the same time, the flow had to be targeted. A plan that incorporated several round-a-bouts was developed to deal with this issue described in figure 4. The project consisted of a total of 6 roundabouts and are in its final stages before presentation to the client.

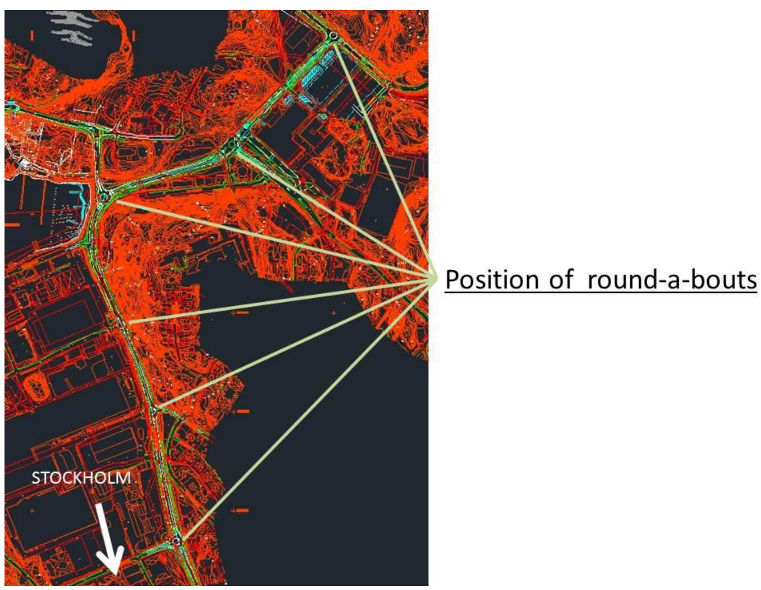

Figure 4: Description of the redevelopment project and its 6 roundabouts.

2 out of the 6 roundabouts were of fairly standardized type with 3 and 4 approaching roads and with close to 90° angle between them. Those are the two most southern ones in figure 4.

5.2 Generated drawings and information with the configurator

Standardized types of roundabouts can be produced in an alternative way by configuring the parameters to match the project specifications. To be able to do this, angles, centerpoints and road width need to be measured and extracted from the original plan to be used as input in the roundabout configurator. The configurationprocess can be seen in figure 3 and the specific design done in this study can be seen in figure 5:

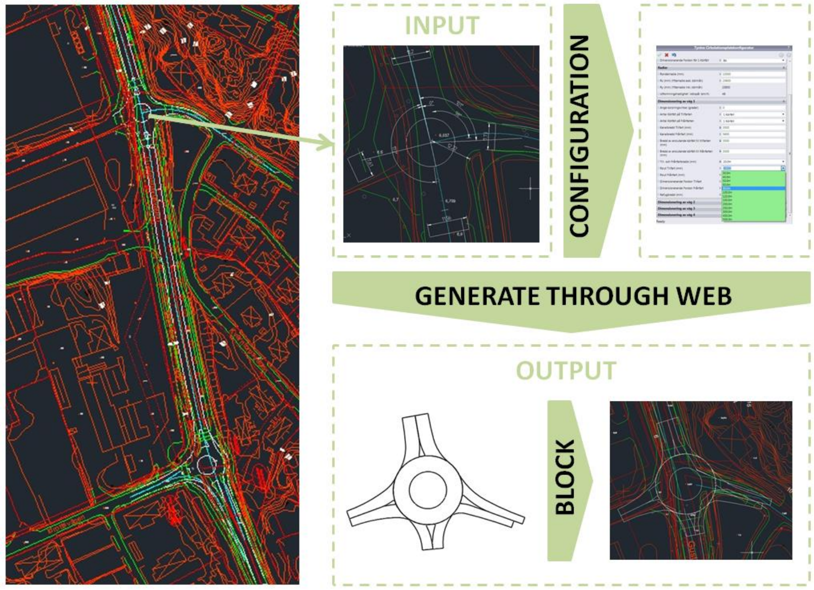

Figure 5: Generation of buildable drawings for a roundabout in the early phase of a project.

The data gathered from the original plan is used as input in the configurator. The output compiles to a dwg-file and can be converted to a block for ease of use. The block can then be put in place in the project to be aligned and connected with existing system. A document is also generated in which you can compare the result of the configuration with the requirements according to the VGU (2012). This particular configuration has less road width than required for the articulated buses to pass through the roundabout in all directions. If the client wants buses to be able to pass through the roundabout from all directions some alterations would have to be made in the landscape and nearby properties.

6. CONCLUSION AND FUTURE WORK

It is technically possible to describe design criteria's into a configurator which subsequently can affect the productivity. By evaluating building products based on mass customization principles, processes can be changed and thus create opportunities for development in addition to the one of a kind process. Through the creation of "products in the product" the possibilities for information transfer and knowledge centralization can be found.

Validation of a previously executed infrastructure project has shown that it doesn't fulfill all the regulations from VGU (2012), which means that the existing ICT-tools could not be used in the technical design phase. The developed configurator that can be used by a nation-wide consulting firm to create buildable products already in the early stages where departure from the norm easily can be recognized for customer and decided upon with the use of the generated protocol. It is also shown that these support tools makes it possible to uniform a large company's knowledge and to confirm a better result than a single consultant could do.

Even though there has been shown that it is technically possible to create these kinds of configurators with the possibilities of creating feedback loops and knowledge storage, the main obstacle seems to be the implementation of the new design process for engineers. Because use of a configurator will expand their work to also include important production constrains such as curbs. These kind of production constrains was previously (to a large extent) ignored by the engineers.

Future work will aim at measuring time savings with the new way of working through the different design phases. Also, feedback from production will be collected to enhance the buildability of the roundabout module. The development of other modules in the company infrastructure platform such as bus stops, bridges and railway crossings that uses the same technics as the roundabout have already started.

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