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STEPS TOWARDS A UNIVERSAL SCHEME FOR PARAMETRIC DETAILING OF COMPOUND TIMBER STRUCTURES

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ABSTRACT: The paper presents potential steps towards a universal scheme for parametrically detailing compound timber structures. Two fundamental concepts are presented: Firstly, a method of combining manual 2D-detailing with parametric modelling, and a secondly concept of simplifying parametric detailing by splitting the detailing process into two. Achievable implications of the scheme are illustrated through a surface-based FEA model of a timber-building. The paper ends by discussing further development steps toward a universal parametric detailing scheme.

KEYWORDS: Parametric detailing, Information models, parametric method development, FEA

1 INTRODUCTION

1.1 BACKGROUND

The Norwegian timber sector is immature, and the industrial potential is underexploited. The market impact associated with an increased degree of completion for timber-based building elements is considerable[1], but the digital infrastructure required for cost- and resource efficient processes are currently fragmented. The digital transformation is suffering from lack of standards for interoperability and from various levels of maturity at the various stakeholders in the value chain. Increased digitalisation has the potential to manufacture cost- and resource effective products faster and with a higher degree of completion. For the timber industry increased digitization has the potential for unlocking a significant production volume of prefabricated elements with a high degree of completion, and therefore to act as an important contribution for the industry to meet climate goals. Parametric modelling has become an increasingly important method in this context and can increase efficiency in both planning, manufacturing, and construction phase. However, the tool is often limited to be applied by specialists, and building a parametric model is a time-consuming process. At worst the expense of developing a parametric model absorbs the profit of increased efficiency in other parts of the process.

Reindeer [2]is a tool that aims to reduce time demanded to prepare a parametric model and to simplify the process of detailing timber structures. However, the tool is limited to 1D-elements, and is not applicable for compound structures such as complete walls and slabs. A main challenge is the number of joint types that occurs in compound structures. Between modules, and between individual components. Hereby, the authors have identified a demand of a further improved scheme for parametric detailing.

1.2 OBJECTIVES

The paper presents potential steps towards a universal scheme for parametrically detailing compound timber structures. The scheme is built around a generic data model, and the output is hence applicable for both architects, engineers, manufacturers, and other stakeholders. Both 1D-elements (beams, columns, etc.) and 2D-elements (CLT, plywood etc.) are included.

In the present study the methodology is implemented in a framework to increase material efficiency, where the structural analysis is used as a vehicle for demonstrating the flexibility and applicability of the method. The case structure is a modular load-bearing building system purposed for multi-storied wooden buildings. The modules are principally standardized, but not fixed in size. Although the case is a building system for tall structures, the methodology has a high re-use value and is working across building systems and makes parametric design available to stakeholders who are not parametric experts.

2 FLIPPING THE MATRIX

The more logically consistent a building system is, the more reasonable the use of a parametric model. A geometric output can largely vary in shape if it is within the same logic. Simplified, one can say that the modular building system consists of four building elements: exterior walls, interior walls, slabs, and roofs. Thus, an intuitive approach is to develop four corresponding parametric modules. However, when taking into account the various the connections between the building elements, the complexity drastically increases while an intuitively clear logic is heavily disrupted by deviations.

The phenomenon is illustrated in Figure 1. Elements that are topologically similar, are coloured similarly. While one wall element is only connected to its parallel vertical and horizontal wall neighbours (grey-green), other walls are corners, connected to the roof, the ground, a slab or

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other combinations. In conclusion: If basing parametric modules on its building element type, the result is a dirty logic scattered by challenging topological variations. This challenge makes the foundation for the flipped matrix and the proposed scheme.

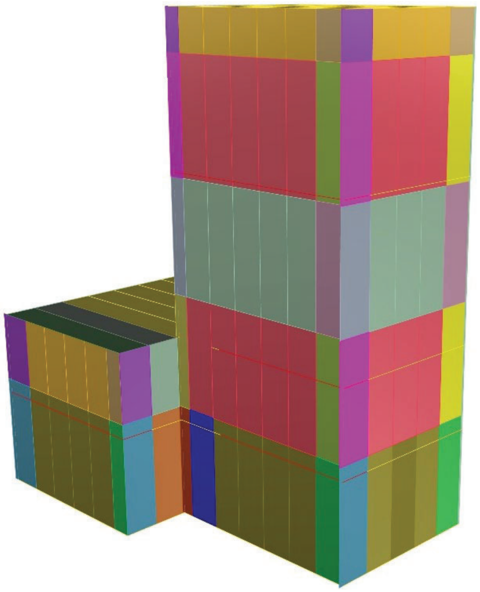

Figure 1: Each color reprents topologically similar elements. Since the elements are connected in various ways, the amount of element types

3 THE PROPOSED CONSEPT

The proposed concept has two main features. Firstly, the concept proposes a two-step detailing method that drastically reduces the complexity and deviations as described above. Secondly, a method of combining parametric modelling and manual detailing is introduced.

3.1 Two step detailing process

The proposed detailing concept flips the matrix. Instead of developing parametric modules based on its main building components, the proposal is to develop a two-step detailing system that firstly takes care of the individual joints between the building elements and secondly detailing the module itself.

This concept allows the single-responsibility principle(SRP) known from programming. A parametric module is now either a vertical connection between main building components or geometric population and detailing internally in a module.

The first detailing step determines the axis, orientations and boundary of the components directly related to the module joints. Knowing the boundary of the module, the internal components can be generated. The second detailing step determines how components within the module interacts, and hereby also determines the length of the components preliminary generated in step one.

The output of the scheme is a light, yet detailed representation of a structure, applicable for multi-scalar modelling[3]. This concept makes it very suitable as a feature in a building design and engineering framework, and the output of the parametric model may easily be adapted to support various design and analysis strategies.

3.2 MANUAL DETAILING

The Single-responsibility detailing principle not only simplifies the parametric model, but also enables the potential of combining parametric modelling and manual detailing. If a joint type in a structure has multiple variations within the same logic, e.g. wall corners with varying angle, a parametric joint can be powerful. However, in many cases, a detail is fixed and scattered in a structure. For such cases, developing a parametric detail is excessive – a manually drawn, fixed 2D-detail is less time-demanding.

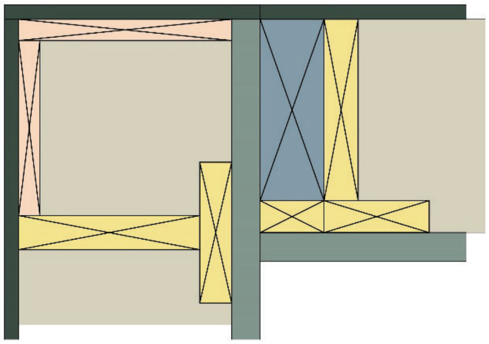

Figure 2: Manually drawn detail

However, an arbitrary 2D-detail is not directly readable by an algorithm. Figure 2 displays a manually modelled corner detail. Further, modern digital fabrication requires fully detailed 3D-models. Hence, it has been developed a rule-set for drawing 2D-details manually and a method for turning the detail into a parametric detail stored in the algorithm. The rules are as following:

1) Any component in the detail requires a parent. The parent is the element the component belongs to in the prefab-phase. In additions, some components might belong to the joint itself. Hence, in a joint where two elements connects, a component is connected to elem0, elem1 or joint. Further, any component requires designated material properties/functional names/purposes. See Figure 3

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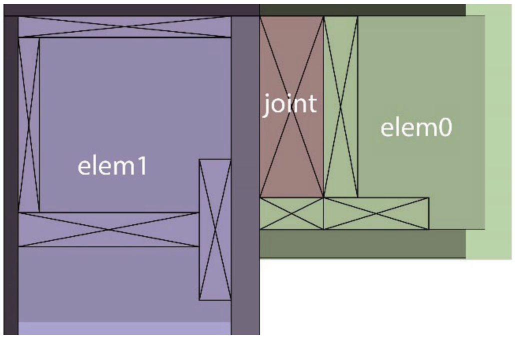


Figure 3: Parent elements

2) The joint requires a local plane. As seen later in the article, the origin of the local plane corresponds to the axis of the joint created from the element's reference surfaces. The X-axis is of the plane is parallel to elem0. See Figure 4

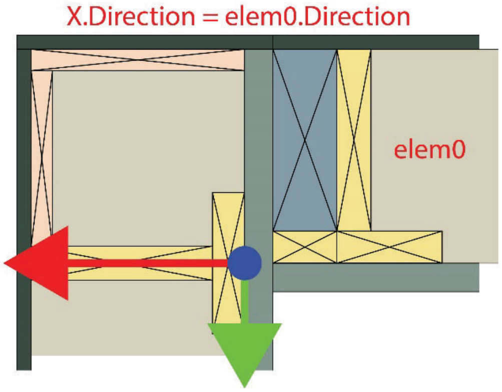


Figure 4: Local Plane

3) A component in the joint has either a defined cross-section within the boundary of the joint, or the cross-section is extend to another joint in the assembly. This is solved by two types of shapes: Closed cross sections are drawn as closed polygons, extended cross-sections are drawn as open U-shapes. See Figure 5

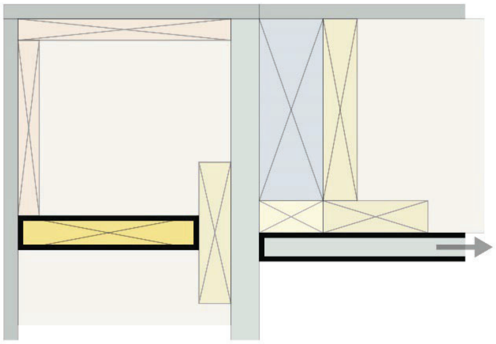


Figure 5: Closed and open cross-sections

Applying the three previous rules, an algorithm can turn the manually drawn joint into a lightweight information model. The joint is wrapped in a block anchored by the local plane. On a superior level, metadata can be connected to the joint it-self. Further, components are described as alpha-numerical enhanced local planes [4],positioned relatively to the main local plane. See Figure 6. Further, Figure 7 renders the data stored in the component's local plane. This is data extracted from the manual drawing, and is the data required to regenerate a physical component.

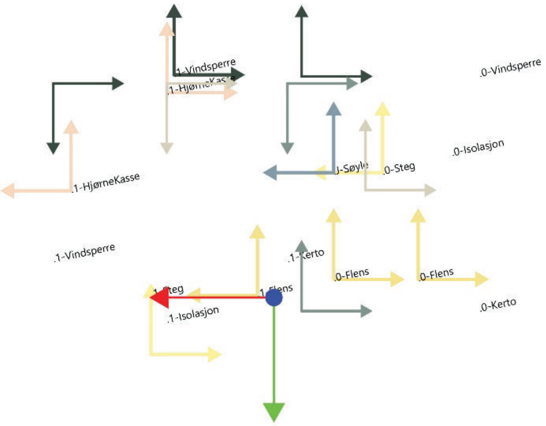
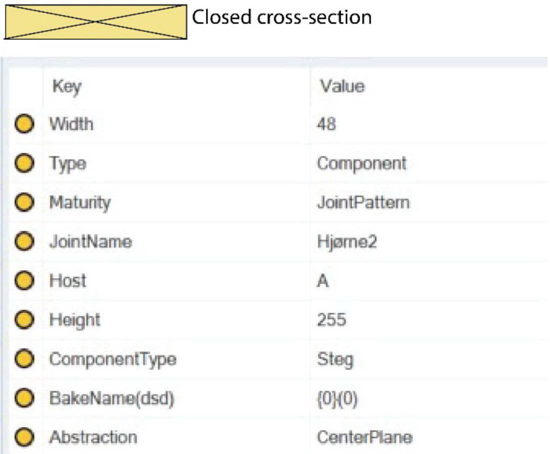


Figure 6: Lightweight joint description



Key	Value
Width	48
Type	Component
Maturity	JointPattern
JointName	Hjørne2
Host	A
Height	255
ComponentType	Steg
BakeName(dsd)	{0}(0)
Abstraction	CenterPlane

Figure 7: Component enhanced with alphanumerical data

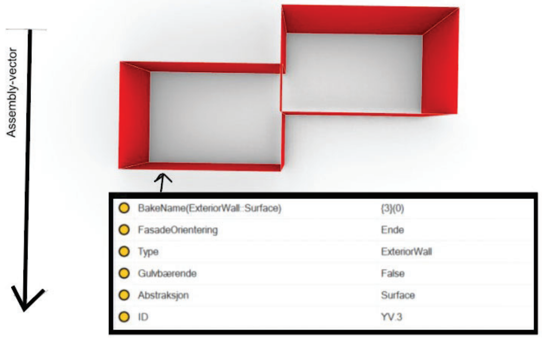
The collection of planes is a simple representation of components in a detail, and contains information about cross-section width, length, element host and detail ID. These 2D-details are oriented to its linear joints, and the detail's components are generated in the assembly.

4 THE SCHEME STEP BY STEP

The proposed scheme consists of individual algorithms that step by step matures a geometric information model from a simplified reference model represented by surfaces and curves to a fully detailed structure. The steps relates to a conventional parametric process and allows manual interactions between each step.

4.1 Normalizing input geometry and register basic geometric properties

For such workflow, the geometric input can vary. In some cases, a manually modelled geometry can be suitable, for other cases the geometry can be parametrically generated. Regardless, the geometry needs to be scheme-based, applicable for extracting precise geometry. The first step consists of cleaning the geometry, normalizing surface-vectors, and not least analysing the geometry and register its basic geometric properties. With help of a defined assembly vector, and the geometry itself, properties such as orientation, determination if the wall is exterior or interior, levels and an initial ID is set.

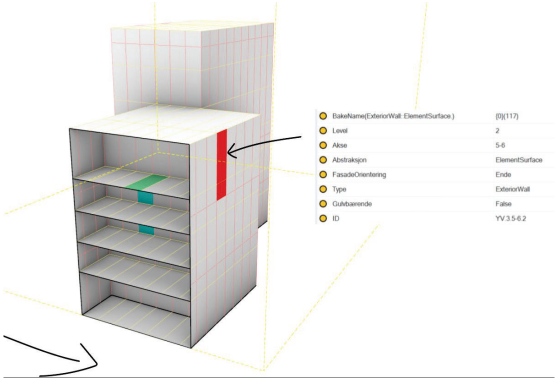


BakeName(ExteriorWall::Surface)	{3}(0)
FasadeOrientering	Ende
Type	ExteriorWall
Gulvbærende	False
Abstraksjon	Surface
ID	YV.3

Figure 8 The geometry itself and the assembly-vector are the basic for basic for registering basic geometry properties

4.2 Dividing geometry into building elements

Most building systems divides its structure into elements. The case structure's logic divides the floors and walls into transportable widths and manufacturable heights. Hence the walls and floors are divided into sub-surfaces, inheriting its properties from its parent wall/floor, but adding information about its related axises and its levels.



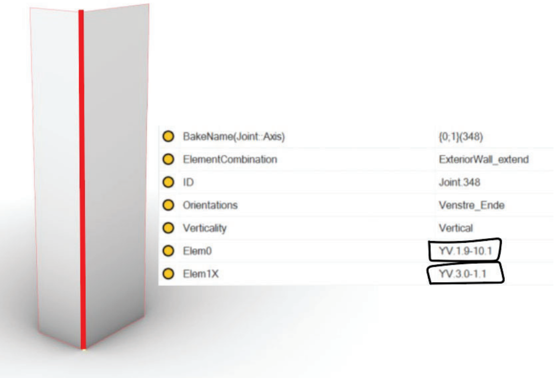
BakeName(ExteriorWall::ElementSurface.)	{0}(117)
Level	2
Akse	5-6
Abstraksjon	ElementSurface
FasadeOrientering	Ende
Type	ExteriorWall
Gulvbærende	False
ID	YV.3.5-6.2

Figure 9. The element is part of its parent wall named YV3, is between axis 5 and 6 and is the third element vertically (2). Hence its ID becomes YV.3.5-6.2

4.3 Register all joints (linear joints) and store geometric properties

Now having all elements generated, the algorithm identifies all joints in the assembly. In this case, linear joints between the elements are the most relevant joints. The algorithm individually searches for joints between exterior or interior walls, between exterior and interior walls, and not least intersection internally between floors and in relation to its walls. The joint itself, is initially just a line and its local plane, but the registered properties and geometric orientation of the joint's walls/floors, and its internal relation, determines what type of joint it is. Following are a few examples:

- A joint between two north-facing walls at the same level, determines that the joint is a horizontal connection between parallel walls.
- A joint between two nort-facing walls, at different levels, becomes a vertical connection of parallel walls.
- A north facing wall and an east facing wall becomes a specific type of corner, and with help of the assembly axis, the joint also consist information about the assembly order of its elements.



BakeName(Joint::Axis)	{0;1}(348)
ElementCombination	ExteriorWall_extend
ID	Joint.348
Orientations	Venstre_Ende
Verticality	Vertical
Elem0	YV.1.9-10.1
Elem1X	YV.3.0-1.1

Figure 10 A joint and its properties

4.4 Categorize joint type instances in the building and map matched joint types

Various joints are modelled according to the description in chapter 2. See Figure 12. Each joint type has multiple geometric requirements for a joint type instance to be applicable. This step analyse all joint instances in the structure and map its suitable joint type. This by orienting the described joint type local plane, to its joint instance local plane.

When the algorithm has finished this stage, all joints are populated with a joint detail represented as a series of property enhanced planes. Further, components in the joints can be extruded according to the length of its joint. Figure 13 displays a corner joint being extruded, while Figure 14 shows the structure being fully populated by the first detailing stage.

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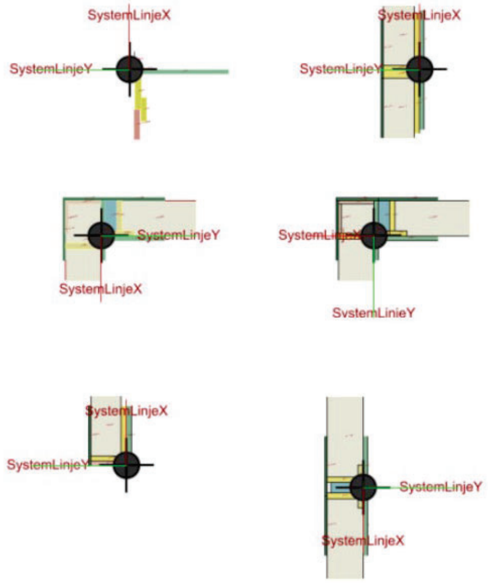

Figure 11 Joint types

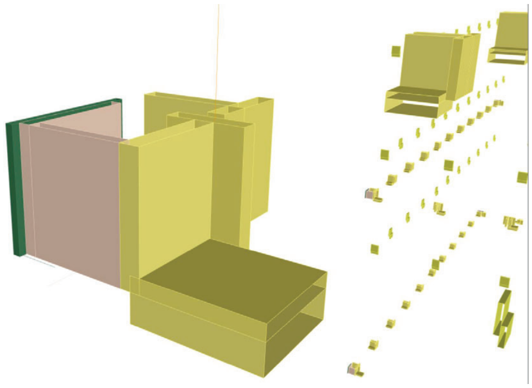

Figure 12 A corner joint being extruded

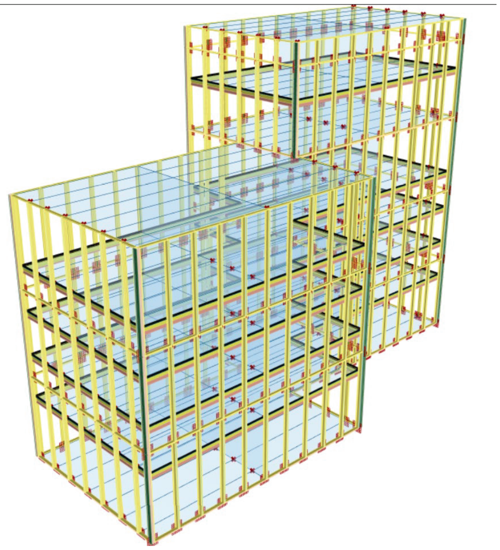

Figure 13: The structure partially populated

4.5 The second detailing stage

Now, the first detailing stage has determined the relationship between the main elements, and the next stage of populating the element itself, is simplified. This due to not needing to take neighbouring elements into account. Figure 15 shows a fully populated model

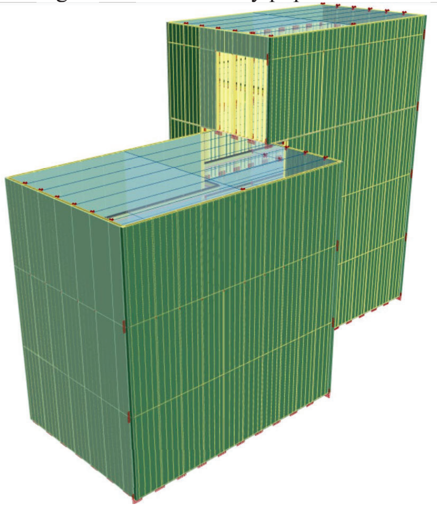

Figure 14 Fully populated model

4.6 Detail component connectons

By the last stage the model is fully populated, but not fully detailed. The last stage, not yet developed in this project, is to detail the connection between the components: the components in the described joints, and the joints made by the components internally in the elements. This procedure can be similar to the steps described in in chapter 4.3-4.4, but in this case, the joint is not a line, but a point in the intersection between two or more components..

4.7 Geometric representation

The above steps displays the components as boxes, but the geometry is still multi-scalar and can be rendered in different ways. By representing the parametric description of the compound timber structure as a surface with associated data, the benefit of object-oriented programming may readily be exploited. In the present project this yielded an efficient method of geometrical representation of the structure. Here additional information such as material model, cost, and embedded carbon emissions may be organized around the surfaces, rather than as a conventional method where this data is organized in logical functions.

The method of parametric description of compound timber structures was advancing in joint development of an element-based building system suitable for high-rise timber buildings. This building system is inherently parametric and modular and comprises solutions for loadbearing exterior and partition walls, flooring system and roof. The building system is based on continuous system planes and system axes from where the parametric rules defining the geometry is referenced, and where loads and linear connections are introduced. This design philosophy allows for a flexible positioning and distribution of both shear connectors and joints between modules. The principle of continuous system planes and system axes is beneficial for a parametric geometric representation, though not required for the scheme for parametric detailing as presented herein.

5 USE CASE

5.1 Methodology to minimise material use

One apparent outcome of the geometric representation is the establishment of an efficient computational finite-element representation of the structure. As a vehicle to demonstrate the potential outcome, a structure generated using this scheme was transformed into a surface-based finite-element model. Due to the object-oriented architecture of the parametric scheme, the base feature of the members associated with a given surface could be defined as beam, shell or solid. For the building system used in the present work, the members have a thickness to length ratio typically less than 0.25 and with transverse shear less important, shell elements are suitable for the numerical model. In Figure 16 a detail of the numerical representation is shown.

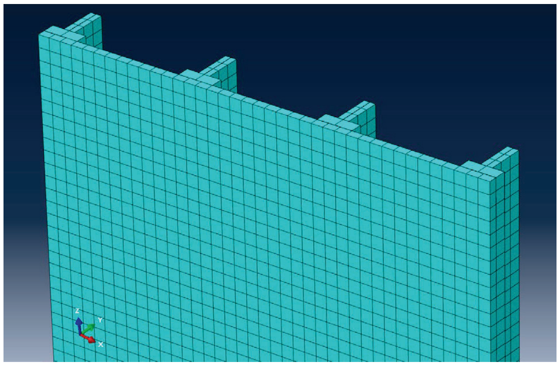

Figure 15: Shell elements with rendered thickness

The methodology permits any information associated with the surfaces to be accessed for a member. In this way the material properties, the associated connection lines of a surface, thickness, and orientation to mention some, are all accessible. Similarly, the properties of the associated connection lines are returned to obtain information about boundary conditions. Principally this enable any property that is stored and associated with a surface to be accessed, making the methodology very powerful and flexible.

This setup allows for easy automation of various tasks. The establishment of a live link between the parametric model and the FEA may be used in an optimization workflow to increase the material efficiency. Here the optimization of the structure may be done with respect to material volume, material cost or embedded CO2 to mention some. The constraints of the optimization is governed by the design code.

The advantages with letting the associated thickness of the shell be a variable parameter in an optimization algorithm may easily be exploited and may offer an efficient computational methodology to minimize material use. Results from finite-element analysis and material minimization of the complete building system referenced in the present work will be published in due time.

5.2 A Twin-transition Tool

The achievable implications of the scheme were assessed during the work of modelling and assessing the structural response of a high-rise timber building employing the building system briefly explained above. In industry 4.0, efficient and practical solutions for digitalisation is crucial. The present work has identified several achievable implications related to digitalisation, and that the methodology may offer an efficient expansion of the toolbox for digital transition of the construction sector.

As described in section 3.1 the scheme is a two-step detailing process, starting with the manual two-dimensional details of the joints of the building system. Due to this the possible implications of the method may be much larger than originally envisioned. Because of the two-dimensional details, the scheme may be used in the mapping of existing built works where only two-dimensional drawings exist. This may aid to digitalize existing built works subject to renovation or extension, and therefore also an expansion of the toolbox for twin-transition.

The methodology is suitable for scalability and may be an additional and valuable tool in the work to build digital twins both for new and existing built works as well as for documentation.

6 DISCUSSION

The paper discusses potential steps towards a universal scheme applied when detailing parametrically. Creating an possibility for inputting manually drawn details into a complex algorithm is seen as promising concept. A key benefit is that the concept democratizes the use of a parametric model – further, time is saved if joint type variations are limited.

The two-step detailing process is seen as promising candidate to ensure single responsibility details, reducing the amount of joint types required. However, more investigation is required. Finally, a potential further development, is to turn the two-step detailing process into a generic, nested parametric detailing process, allowing infinite levels of parametric details within a parametric details.

ACKNOWLEDGEMENT

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