Modelling Precast Concrete for a Circular Economy in the Built Environment

Level of Information Need guidelines for digital design and collaboration

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In recent years, there has been a growing interest in adopting circular approaches in the built environment, specifically reusing existing buildings or their components in new projects. To achieve this, drawings, laser scanning, photogrammetry and other techniques are used to capture data on buildings and their materials. Although previous studies have explored scan-to-BIM workflows, automation of 2D drawings to 3D models, and machine learning for identifying building components and materials, a significant gap remains in refining this data into the right level of information required for digital twins, to share information and for digital collaboration in designing for reuse. To address this gap, this paper proposes digital guidelines for reusing precast concrete based on the level of information need (LOIN) standard EN 17412-1:2020 and examines several CAD and BIM modelling strategies. These guidelines can be used to prepare digital templates that become digital twins of existing elements, develop information requirements for use cases, and facilitate data integration and sharing for a circular built environment.

Keywords: Building Information Modelling (BIM), Circular Construction, Reuse, Concrete.

INTRODUCTION

The Circular Economy (CE) concept has garnered significant attention across several industries, including the construction sector (Benachio et al., 2020). Buildings and construction in Europe are responsible for more than half of the materials extracted and generating more than a third of Europe’s waste (van Eijk et al., 2021). Additionally, the Waste Framework Directive in the European Union (EU) requires a minimum of 70% of non-hazardous construction and demolition waste (CDW) to be prepared for reuse and recycling since 2020. The waste hierarchy of the European directive prioritizes the prevention of waste, and subsequently for reuse, recycling, recovery, and disposal as a last resort.

A large share of the mass housing stock in Europe was built during the 1960s and 1970, with a significant proportion utilizing load-bearing large-panel precast concrete systems (Huuhka et al., 2015). Many residential buildings have either been demolished or are being considered for demolition due to various reasons, including having exceeded their functional lifespan, requiring renovation, and in most cases, for reasons other than structural capacity. Huuhka et al. (2015) explored the reuse potential of precast concrete panels in the Finnish housing stock. Their findings indicate that compared to current norms, precast panels could be reused to
design detached houses corresponding to about a third of Finland’s annual residential construction. In Sweden, a quarter of the housing stock was built in a relatively short period between 1965 and 1974, with more than a million units constructed during what is known as the ‘Million Programme Era’, using various industrialized and prefabrication methods (Stenberg, 2013). Given that precast concrete elements can have longer lifespans, their reuse in projects can contribute to substantially reduced carbon emissions by avoiding the production of new concrete. Although many of these buildings were not designed to be deconstructed in the future, practices aiming to reclaim elements for reuse can also reduce the waste generated during demolition.

This paper aims to propose digital guidelines for precast concrete reuse, based on the Level of Information Need (LOIN) standard EN 17412-1:2020. The LOIN is also undergoing development as an international standard with ISO 7817. The following section presents an overview of pertinent research efforts, followed by an explanation of LOIN and an outline of the proposed guidelines. Subsequently, a comparison of modelling strategies across a set of criteria is conducted for popular CAD (computer-aided design) and BIM (building information modelling) tools commonly employed in the construction industry.

Background of efforts
In their recent study, Küpfer et al. (2023) discovered that the reuse of concrete has been successfully implemented in real-world case studies dating back to the 1960s. Their findings suggest that reuse could be a key strategy in creating a sustainable built environment. Reuse can take different forms, such as the on-site reuse of existing buildings in Lacaton & Vassal’s ‘Tour Bois le Prêtre’ in Paris, or selective deconstruction as demonstrated by 3XN’s ‘Quay Quarter Tower’ in Sydney, which repurposes a part of the existing structure. Moreover, piecewise reuse of building components can be done through deconstruction and reassembly into new structures, or repurposing for new applications such as the ‘Re:Crete footbridge’ (Devènes et al., 2022). However, the highest value for precast concrete is when elements retain their original function.

Direct measurement, photogrammetry, laser scanning, or a combination of approaches can be used to gather data manually or automatically for existing buildings (Skrzypczak et al., 2022). However, scan-to-BIM approaches often rely on using scan data only as a reference in BIM tools. Kovacic & Honic (2021) emphasize the need for automating the process and propose using ground penetrating radar (GPR) to gather material information. Kaufmann et al. (2022) developed an initial framework for scan-to-BIM automation through machine learning, which involves using point clouds to recognize structural elements. Available workflows can generate a 3D model in an open file format like Industry Foundation Classes (IFC) from a 2D plan (Plans2BIM, 2023). However, these models represent generic elements without specified information. Other research investigated urban mining approaches based on machine learning to identify components from existing buildings (Raghu et al., 2022), and BIM-based methods to assess material intensities and integrate with GIS (Honic et al., 2023). However, a significant gap remains in refining digital models to the right level of development required by designers and for collaboration among actors. Furthermore, it can be argued that the possibilities of sharing models within Common Data Environments (CDEs) or digital marketplaces and platforms, to collaborate and leverage data in the reuse process, have yet to be fully explored and utilized.

Level of Information Need framework
The LOIN is described in EN 17412-1, a standard developed by Technical Committee CEN/TC 442, which focuses on BIM-related standards (European Committee for Standardization (CEN), 2020). LOIN is a ‘framework which defines the extent and granularity of information’. The standard describes the concepts and principles for developing information deliverables e.g., digital models to be shared for the
design teams and organizations when using BIM. LOIN aims to establish a methodology that applies to the whole life cycle, from planning, design, construction, operation, and end-of-life of buildings. LOIN is also different from previous conceptions such as the still-in-use Level of Development (LOD) from BIMForum in North America, and the Level of Detail (LOD) in the UK as described in PAS 1192-2 (now superseded by BS EN ISO 19650-1 which also introduces the LOIN concept). In PAS 1192-2, LOD metrics were set in a standardized nomenclature of graphical and non-graphical information, numbered from 1 to 7. These metrics were too generic, associating geometry and information, and sometimes dissociated from the use case. The LOIN framework allows for complementary but independent geometrical and non-geometrical metrics. For instance, a higher level of information does not necessarily require higher geometrical detail. This is relevant when considering the reuse of concrete and other building components when moving from the deconstruction phase towards reuse. EN 17412 also argues that when there is too much information, it results in the overproduction of deliverables and information waste. See Figure 1 for an overview of the LOIN framework.

Figure 1
Overview of the LOIN framework in EN 17412-1:2020

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Milestone</th>
<th>Actor</th>
<th>Object</th>
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<td>Why</td>
<td>When</td>
<td>Who</td>
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<tr>
<th>How</th>
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<tr>
<td>Geometrical information</td>
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<tr>
<td>Detail, dimensionality, location, appearance, parametric behaviour</td>
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<tr>
<td>Alphanumerical information</td>
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<td>Identification, information content</td>
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<tr>
<td>Documentation</td>
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<tr>
<td>Set of documents</td>
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**METHODS**
Standardized information can facilitate information exchange and a CE for buildings by ensuring that digital models contain relevant data and are readily available to stakeholders. The objective of this study is to propose digital guidelines based on LOIN for the reuse of concrete and use its geometrical aspects as a reference for analysing modelling strategies in CAD and BIM tools. ‘Building Product Models’ is a term that was initially used to describe what is now referred to as BIM (Afsari and Eastman, 2016). Creating and sharing models entails producing structured information, including protocols for naming, use of classification systems, file formats, and standard properties for objects. Digital marketplaces typically offer standardized models for proprietary CAD and BIM tools, as well as software-agnostic file formats such as the IFC. In this study, CAD and BIM strategies for modelling reusable precast concrete elements are explored for two commonly used tools that are Rhinoceros 3D and Revit. Rhinoceros or Rhino is a CAD tool that also supports parametric design and analysis workflows in Grasshopper and its plugins. Rhino also has API connections to several BIM tools. Thus, the use of Rhino is growing among architects and engineers in the construction sector. Revit is a widely used BIM tool for modelling architectural, structural, and building systems. While Revit has native support for IFC, Rhino requires the use of third-party plugins to enable IFC capabilities.

**Framework for reuse modelling**
Both this paper and EN 17412 do not predefine the specific purposes of information exchange, or the actors involved, as doing so would limit its applicability. Nevertheless, different use cases, project milestones, or stakeholders may require varying levels of information. To address this need, guidelines and digital templates can be instrumental in modelling a digital representation of physical precast elements. When elements are selected for reuse, a digital instance/twin can be created using one of these templates. A unique ID is then assigned to each physical object and its digital instance. New data can be stored in the digital twin when this becomes available.

The LOIN framework describes three aspects that are: geometrical information, alphanumerical
information, and documentation. These aspects are described in the following sub-sections. Another reason for not attempting to pre-define LOIN for each use case is that unlike in the production of new elements, information for reuse is gathered gradually from real objects, and updated in the digital counterpart/twin, using only the data relevant to the reuse scenario. For example, a concrete scanner (also called ferroscan) can be used for rebar localization, depth of the first layer of rebars, and diameter estimation. This type of information can be compared with drawings and can be added to the model a) as a modelled rebar or reference lines, or b), as properties of the model. Option b may be sufficient in some reuse cases, since the original drawings may be available, and only need to be linked to the models.

**Geometrical information**
The five aspects of geometrical information in LOIN are (1) detail, (2) dimensionality, (3) location, (4) appearance, and (5) parametric behaviour. Geometrical aspects are critical for reusing concrete. For example, knowledge of the prefabrication system, such as dimensions of elements (i.e., length, width, height) is needed to evaluate suitability for reuse and incorporation into a new building design.

The (1) detail of the geometry of precast concrete is relatively simple for any design stage and it should include any voids or topological features. While rebars may be needed for specific purposes, they are not addressed in this study, and neither is the type of connector between precast elements. The latter is relevant for structural design and reassembly and dependent on a series of steps, such as the reversibility of the existing connection, the deconstruction process, or the design of new connectors for reassembly.

Regarding (2) dimensionality, objects should be modelled in 3D. In addition, 1D or 2D representation can be derived from views/projections, or workflows, and can be useful for the algorithmic design of new structures.

Regarding (3) location, elements may include a property with the address of the donor building and/or production factory. Part of our ongoing research is identifying and tracking elements through technologies such as Radio frequency identification (RFID) and linking them to BIM models and material passports. This will help identify and locate elements before deconstruction, during transportation, and after reassembly. The location also concerns the position and orientation of objects. For instance, in an algorithmic design workflow, the orientation and position of walls and slabs are important, if elements are to maintain their functional characteristics, as well as sufficient load-bearing capacity in the reassembly of a new project.

The (4) appearance of the elements can be in wireframe mode, shaded or rendered with textures. In addition, BIM tools usually represent elements as newly produced and differentiate by phases such as existing conditions or new construction. The representation of materials and degradation that may be needed for specific use cases can be explored in further work concerning quality assurance for reuse.

Although reuse entails starting from existing elements with fixed dimensions, (5) parametric behaviour may be needed. For instance, elements with similar characteristics of a prefab system and categories, such as a type of wall, may be part of the same template. The parametric behaviour is useful for having one class of objects (e.g., Revit family) and creating types. In addition, elements may be cut for reuse, and this can be reflected by creating new ‘Types’ by using the parameters associated with the dimensions. In some cases, knowledge of rebars will be needed to determine the possible cutting patterns for elements and the remaining structural performance. For instance, hollow core slabs have a uniform section, that when cut, can result in even better structural performance due to a smaller span, but this may not be the case for precast walls.

Parametric behaviour also relates to dimensionality and location depending on the modelling procedure e.g., constructive solid
Alphanumerical information

In EN 17412, alphanumerical information refers to objects’ identification and information content i.e., properties/attributes. Identification concerns aspects like naming, classification system or breakdown structure, indexing in a CDE, and object properties. An initial set of properties for reuse can be the year of construction, planned deconstruction, structural capacity, internal or external element, covered or exposed, carbonation depth, and rebar depth and diameter.

The grouping principle of classification systems is either enumerated (i.e., hierarchical) or faceted (Afsari and Eastman, 2016). A hierarchical grouping cannot add new objects and would require regular revision for new objects, while in a faceted classification, sub-classes can be combined to create new objects. Prefabricated concrete systems were designed for specific functions at the time of production. When reusing these elements for different purposes, additional measures may be necessary, such as cutting or the use of new connectors for reassembly. Therefore, there is a need for a faceted classification for reusing precast concrete. See Figure 2 for an example from our previous construction pilot on the need for faceted classification. Furthermore, objects should be mapped to the latest IFC schema and consider descriptions and properties available from the buildingSMART Data Dictionaries (bSDD).

ISO 19650-1 explains that digital models (also called information containers in BIM standards) should be named following an agreed convention. The naming helps to make documents and models retrievable in search queries in a CDE. This is also useful for sharing in digital marketplaces. Furthermore, when sharing in a CDE, ISO 19650 recommends adding a revision code and status information i.e., work in progress, shared, published, and archived.

An example of the naming convention is:

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<CountryCode>_<OriginatorCity/Factory><YearBuilt>_<Class>_<Type>_<InstanceNumber>_<Revision>
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Documentation

The third component of LOIN is documentation. Concerning reuse, documentation is represented by the initial set of drawings and documents of the existing building. Documentation may also refer to information related to the digital model such as a material passport, environmental product declaration (EPD), life cycle assessment (LCA), laboratory test results, or the database of available elements for reuse. The digital models can support documentation purposes by linking to the material passport and other data sources in and out of the CDE through an Application Programming Interface (API) service. For instance, the geometry and information of digital models can be used to exchange data bidirectionally in the CDE, with external collaborators, and/or public services.
RESULTS
The LOIN framework described previously is illustrated in Figure 3. This section focuses on the geometrical aspects of LOIN and analyses different modelling strategies in a BIM and a CAD tool. Alphanumerical information can be added to digital models and is being addressed in our ongoing research on logistic aspects such as tracking elements, material passports, digital twins, and quality assurance.

BIM modelling for reuse
Precast panels for reuse can be created starting from a) drawings, point clouds, models, or other data capture methods, b) a template of the precast panel, or c) through a combination of approaches. Then, objects should be loaded, copied, and updated along the digital workflows for reuse. The following paragraphs examine the various modelling strategies in Revit, each assigned a number and evaluated against a set of criteria, which will be summarized in Table 1.

Sharing digital models is an important aspect of reusing building elements, since the object behaviour, should be as ‘loadable BIM objects’. Objects such as walls, floors, ceilings, and stairs in Revit represent ‘system families’. System families are part of the project template and can be edited, copied, and pasted, but cannot be shared as loadable BIM objects in external files to the project.

A precast element’s geometry and appearance should not be merged with other objects, which is not the default behaviour for walls in Revit (1) and needs to be fixed manually for every instance by ‘splitting walls’ or ‘disallowing joints’. Walls can be counted in Revit schedules, but when walls are merged, the result is one instead of two objects. Static behaviour is needed for modelling precast elements, and the lack of it can result in errors and rework. Thus, modelling precast with the wall tool (1) in Revit can be challenging. Vertical or horizontal features, ‘reveals’ in Revit (2), can be added to walls to distinguish joints of geometry, but this approach is manual with no geometrical separation, thus not possible to tag or count individual panels. Horizontal reveals can be added to a Wall Type, but it is useful in a few cases when this is a geometric feature of the panel. Another method that can result in precast appearance, but no separation of elements, is through a foreground pattern and spacing of it to the panel’s length. This method is shown in Figure 4, but not included later in Table 1.

Floors (3) have a static behaviour in Revit by default, meaning that they do not merge with other floors. In the case of precast elements such as hollow core slabs, their geometry cannot be modelled with the Floor tool (3). Hollow cores can be modelled either through a ‘Generic Model’ family (4) or a ‘Model in Place’ (7) as a Floor category. Although Generic models support having multiple objects (i.e., Family and Type in Revit), and therefore parametric and static behaviour, they cannot be assigned a system family category. In the case of walls, generic models cannot define a room or host windows and doors. This is a considerable limitation, and any further digital design progression, after the rearrangement of precast elements in a new design, would require remodelling with the Wall tool (1). Voids can be modelled for strategies 1, 3, and 4, such as for the passage of building systems.
By default, volume quantities can be scheduled for generic models, but not the areas. Object dimensions (i.e., length, height, width) can be added to the generic model as properties and subsequently used in a formula for area calculation. Generic models can be loaded as external BIM objects, but as explained, this approach had some limitations. Regarding classification and open standards, Generic Models can store the assigned classification system and can be mapped to an IFC entity (e.g., IfcWall).

A further option is to use Create Parts for a Wall in Revit (5). This technique subdivides a wall into parts with a fixed length, and a gap between parts can be added. When only Parts are shown in the model, objects cannot be moved. However, both ends of the wall can be extended, thus changing length. The wall can also merge with another wall, thus not having static behaviour. Total quantities can be scheduled, and panels from parts can be counted. Parts can host doors and openings or be deleted from the Wall (e.g., one precast panel), but cannot be substituted with other wall types. The whole wall and type would need to be substituted. Parts can be created also for Floors in Revit.

Parts (5) can also be used to first define precast panels, and then use the ‘Precast Tools’ tab in Revit (6). Precast tools support only elements created with tools of the Structure tab in Revit. This set of tools can be configured to convert modelled walls/floors into precast assemblies with detailed geometrical appearance and gaps, add mounting elements, add reinforcement, and generate shop drawings. However, Precast tools (6) fix an object’s location, and cannot be saved as a loadable object, or copied without issues to other projects.

Another method to make a static behaviour for walls is through Model in Place (MIP) (7). This method can allow for static behaviour, but if the object is copied, new instances are not related to the starting object. Scheduling of MIP objects is also challenging, as in the case of an extruded geometry, the quantity would correspond to the footprint and not the wall’s vertical surface. A workaround is to create a group of the MIP while in the editing mode and save it in the ‘Library tab’ as a ‘Group’ (8). This option saves the object as a Revit ‘RFA family’ (not possible with the out-of-the-box tools), that can be loaded. The RFA object behaves as a loadable family and belongs to the Wall category, is controllable by parameters, and...
has a static behaviour (8). Geometrical dimensions can be used to have a parametric model, and as a Revit family, multiple object types can be supported. In addition, elements are countable and can be scheduled with ‘shared parameters’.

Another modelling strategy is through ‘Curtain Walls’ (9). Wall families can be placed in the ‘curtain panel system’, and for the spacing, the length of precast panels can be used. However, this modelling approach is not suitable for placing single elements, although it can be a valid method for precast facades. The wall panel in the Curtain Wall is also ‘room bounding’. Wall panels can be counted in Curtain Panel schedules, but not in Wall schedules where they appear as one with the total area in m².

**Modelling for reuse in CAD**

CAD capabilities were tested for Rhino 3D, which supports various modelling techniques including meshes, non-uniform rational basis splines (NURBS), and Subdivision Surface (SubD). Each geometry can be given attributes, called ‘Attribute User Text’ in Rhino. Attributes can be exported to an external file in a spreadsheet. Attributes can also be imported and assigned to an object or ‘matched’ to multiple instances. Attributes can also be assigned to multiple objects using Grasshopper or other scripting tools for computational design use cases.

‘Groups’ can be used in Rhino for precast, but copying a group creates a new group entity. Instead of groups, ‘Blocks’ in Rhino can be copied, modified, loaded, and managed with the ‘Block Editor’ (10). Blocks can also host other blocks (i.e., nested blocks), like ‘nested families’ in Revit. It is possible to retrieve quantities and count elements when using Blocks. Blocks have a static behaviour, and their geometrical appearance can be modified in the block editor. Blocks can be embedded and/or linked from other Rhino files. This is relevant as allows for storing and retrieving elements from a CDE for digital collaboration.

The IFC entity and classification can be added as attributes. Rhino objects can be filtered based on geometry type, block name, attributes, element name or ID. Selections can also be saved for quick retrieval, enabling a customized way of the equivalent of ‘Filters’ or ‘Model Categories’ (e.g., Walls, Floors) in BIM tools.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>1 Wall tool</th>
<th>2 Wall tool + reveals</th>
<th>3 Floor tool</th>
<th>4 Generic models</th>
<th>5 Create Parts</th>
<th>6 Precast tools</th>
<th>7 Model-in-place</th>
<th>8 MIP+group +save</th>
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Table 1

Comparison of modelling strategies in BIM and CAD for precast walls and floors for reuse. Strategies are for Revit, and only the last column (i.e., Blocks) is in Rhino.

+ Yes; - No; (+) partial/limited alignment to criteria
DISCUSSION

The LOIN standard can be used as a framework for specifying the required level of information throughout the lifecycle of a precast concrete element or structure. The standard can help define the minimum requirements, including geometric, physical, and other characteristics, to refine captured data into digital models to support component reuse for a CE in the built environment.

The comparison of modelling strategies focused on LOIN’s geometrical aspects. BIM modelling was tested through each criterion where object behaviour was checked in Revit across schedules, the project browser tab, and Type and Family editors. Certain Revit strategies are more effective for designing new buildings and each modelling strategy goes with pros and cons. For example, Precast Tools don’t allow moving elements or copying parts. Also, it is not always possible to switch between strategies, such as swapping a Wall panel in a Curtain Wall (9) with a detached element (1), or from Parts (5) to detached elements (1). The paper also showed some useful workarounds such as using Generic Models or the ‘MIP and Group’ (8) technique. BIM modelling strategies can be combined such as employing Generic Models or MIP for the internal structure, and Curtain Panels for the façade. The identified limitations may be analogous to other BIM tools. In future work, these strategies will be applied in a case study to further explore their effectiveness when including objects originating in other models, and different methods and tools.

For CAD, fewer strategies may exist with fewer capabilities than BIM but still allow for achieving the criteria. For example, precast can be modelled in Rhino with Blocks. The interaction between CAD and BIM strategies can be explored in further research. Future work aims also to explore algorithmic design capabilities with Grasshopper. Although the investigation is limited to one CAD and one BIM tool, the criteria can be valid to evaluate other tools. The comparison can be useful for researchers addressing circular construction and practitioners aiming to design for reuse. A wider future review could consider more BIM platforms and open-source tools such as Blender and its BIM Add-on which enables authoring IFC files through the IfcOpenShell toolkit. LOIN’s alphanumerical aspects facilitate information management and sharing and promote interoperability. Future related work will explore logistical aspects such as tracking physical elements and material passports. Additionally, the data will be utilized to estimate environmental impacts/benefits of reuse with visualizations to support decision-making. A classification for precast systems will be developed in further studies and could be combined with a faceted classification system like CoClass, to define and share information in reuse projects. Supporting CAD, BIM, and open standards like IFC is crucial as stakeholders may use a variety of tools, and interoperability becomes essential as information needs to be exchanged for different purposes. In addition, digital models will integrate various data sources to achieve full digital twin capabilities.

CONCLUSIONS

To facilitate a CE for buildings, data needs to be captured, managed, and shared among stakeholders. Although previous studies have been concerned with capturing data on buildings and materials, producing the appropriate level of information for digital models to reuse building components remains underexplored, especially for precast concrete which is of interest to several research efforts in Europe. This paper addressed this gap by proposing digital guidelines for reusing precast concrete based on the LOIN framework in EN 17412. BIM and CAD modelling strategies were evaluated concerning criteria from the proposed reuse modelling framework, to share structured models for digital design and collaboration. In future work, the digital twins of reused elements will be integrated with material passports, tracking tags, and sustainability evaluation workflows. Case studies will be conducted to support decision-making for circular construction. These efforts will exemplify the complete application and utilization of the LOIN framework.
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REFERENCES