



# Adaptive Reuse of Architectural Heritage

Jan Buthke<sup>(✉)</sup>, Niels Martin Larsen, Simon Ostenfeld Pedersen,  
and Charlotte Bundgaard

Aarhus School of Architecture, Nørreport 20, 8000 Aarhus C, Denmark  
jb@aarch.dk

**Abstract.** How can we, through the use of digital technologies, create qualitative and sustainable transformations of our architectural heritage? This project of reference spans across the fields of architectural heritage, digital design and fabrication, and circular economy. As both an interdisciplinary, research-oriented demonstration project and a built project, it has a built-in outreach through a number of external partners involved.

The paper describes the architectural investigations and solutions developed in the intersection between architectural heritage, digital registration processes and parametric construction and fabrication systems. The method presented, establishes a design workflow that relates detailed information of existing conditions with production constraints. A key aspect of this novel method is the emphasis on modular principles, which, together with the integration of digital technologies, allows the construction costs to be minimized. This makes restoration of historic buildings that holds high cultural and architectural value, but low economic value, a viable alternative to demolition.

The paper describes how we, using digital technology, can tailor materials into bespoke building components with a clear notion of materiality in architectural transformation projects. The paper addresses the reuse of architectural heritage through digital technologies and investigates a design pipeline for the manufacturing of bespoke building components with the capability to adapt to an existing building fabric.

**Keywords:** Adaptive reuse · Digital technologies · Architectural heritage

## 1 Adaptive Reuse

Due to changes in demography, industry and production methods, many smaller local communities are challenged. Buildings of local cultural importance are abandoned as a result of changes in production methods within agriculture and industry (Hansen et al. 2013). The architectural heritage is often an important carrier of identity, especially in rural areas that have developed around a monoculture and where the economy is based on one primary activity, such as fishing industry, trade, mining or a fabrication of a specific product type (Proshanky et al. 1983).

Heritage buildings in such communities are decaying and being demolished in favor of new buildings that are more functional. This means that a loss of identity and history takes place. To counteract this mechanism, we suggest adaptive reuse of these historic buildings. Often, restoration of these functionally obsolete buildings is

relatively costly, and a key challenge is to find methods that economically can compete with demolition of the architectural heritage and subsequent realization of new buildings using industrialized building methods. The development of the case project described in this paper led to a search for sustainable, economically and qualitative alternatives. As a result, a workflow with a modular approach that makes use of laser scanning and parametric design tools and a combination of craft and CNC fabrication has been developed. The program for this demonstration project is the installation of five apartments in an existing factory building from 1905. Aarhus School of Architecture made a partnership with the Municipality Faaborg Midtyn to realize the project, which has received full support from the Danish Transport, Construction and Housing Authority.

## 2 Digital Technology and Modular Construction

### 2.1 The Strategy

Laser scanning of the existing architecture and modular construction systems are key aspects of the alternative approach to the transformation of architectural heritage that is presented here. Especially where the economic value of the historic buildings is low, and the cultural value is not sufficient to secure preservation by the authorities, the method can be relevant as an alternative to demolition. We present the method as a strategy for this type of transformation projects, and the specific choices and techniques described for the factory project should be seen as an example of a development process as it was possible in the current circumstances rather than an optimal solution.

An analysis of the cultural value of the existing architecture is the first part of the method. Then, a deep 3D scanning of both the exterior and the interior of the existing architecture is carried out. From the point cloud, selected parts are translated into geometric formats that can be directly addressed as part of the design of the transformation project and carried forward for fabrication. The program for the transformed building(s) is now compared with the current architectural context to find the best placement of main functions and technical installations. At this stage, possible strategies for realizing the transformation through the use of a modular system are analyzed. In a typical industrial approach, modular systems have their best use when there is a simple adaptation to the existing context, however, what we put forward here is to use parametric design techniques and digital manufacturing technology to obtain a smooth connection to the existing architecture. The production of the modules and the preparation of the existing building can happen simultaneously; thereby leading to a short and less expensive realization process, compared to traditional on-site adaptation, which in our case would have been a very time consuming undertaking based on manual labor due to the irregularly geometry of the building.

In short, detailed design decisions early in the development process and precise adaptation is made possible through the use of laser scanning and robotic fabrication. Using a modular system reduces costs and the length of the construction period, and the digital platform that holds information about all phases of the project, from registration

to fabrication helps to increase precision and reduces the time spent on site for adaptation.

## 2.2 Assessment of Architectural and Cultural Value of the Existing Buildings

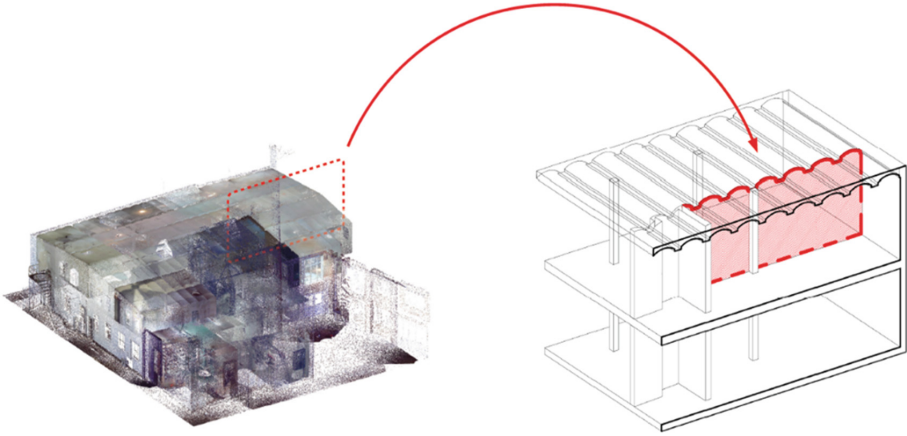
To detect important elements that need to be preserved, a value assessment of the existing architecture is carried out. The analysis shows what parts of the buildings(s) are least vulnerable in terms of losing architectural value as a result of the transformation process (Jokilehto 1999). Cultural environment, the function of the building(s), the space plan, the architectural expression, the history and the use of materials are examples of conservation values that are evaluated and described in a written report. The value assessment is a qualitative assessment and forms the foundation for subsequent decisions regarding the development of the transformation project (Randall 2002).

For a factory building as the case described here, the assessment of values is different from that of other types of building, i.e. a train station or a town hall. Industry buildings are generally characterized by rationality and they often have many interventions and expansions due to changes in functionality and production volume over time. As such, it can be considered a natural adaptation to the current situation to convert these buildings into housing, especially if the value assessment forms the basis for the transformation (Anker 2007).

## 2.3 Scanning the Existing Architecture

For analysis of architectural heritage, laser-scanning technology is widely used, and a line of research is devoted to translating the point cloud formats to 3D modelling environments (Boulaassal et al. 2010). Part of this challenge is to define the sufficient level of detail in the translation (Fai and Rafeiro 2014). Similarly, in our setup, we seek to establish a data set with the amount of geometric information that is exactly sufficient to support the project development and the adaptation to the existing architecture. In the project case, a Faro 3D Focus laser scanner is used, but this could be replaced with other types of laser scanners or scanning techniques with sufficient precision and reliability. First, a complete point cloud of the existing building is produced. This initial scanning forms the basis for the project development. When crucial meetings between existing and new have been located during the design process, another set of scans are carried out to ensure precise adaptation. The required tolerances vary between the initial first scans and the later more in detail scans. A tolerance of 25 mm in the first scans is sufficient to being able to develop the transformational concept. The later in detail scans, which inform the design and manufacturing of the modules must be as low as 1–5 mm to make sure the prefabricated parts will fit in place later.

As shown in Fig. 1, strategically chosen vertical and horizontal sections of the point cloud are transformed into light-weight, but precise, geometric representations to be used directly in the design-to-production process. In this way, excessive amounts of data in the workflow are avoided, and at the same time, it is possible to reach back to the original point cloud and extract further information when necessary.



**Fig. 1.** From the point cloud, curve geometry is extracted to define the contour of the wall

## 2.4 Using Modular Construction Systems

Adaptation to the existing architecture can be improved through the use of robotic fabrication technology that allows customization of building components (Kolarevic 2005). These digital production technologies can support a more sustainable, economical and adaptive transformation of the architectural heritage (Lylykangas 2011). The access to digital fabrication technology is combined with a flexible modular system in order to secure efficient montage and high quality of the architectural result, both in terms of detailing and technical standard. In terms of the general method, the modular principle can be understood as either a room-size module a wall element or even a smaller component, depending on the character of the project. Regardless of the specific solution, it is important, at this stage, to work closely with contractors to ensure that the design solution is viable, especially in relation to the use of digital fabrication technology, which often has particular constraints (Fig. 2).



**Fig. 2.** Modular construction system based on plywood sheets and CNC

### 3 Demonstration Project

The task of the demonstration project is to develop and construct a housing project in an existing factory building from 1905 in the small town Ryslinge, which will be able to compete with corresponding conventional housing construction. The demonstration project is carried out in a Factory Building (Fabers Fabrikker), that only recently had lost its original function, is transformed into a housing complex, containing five different size apartments (Fig. 3).



**Fig. 3.** Fabers Fabrikker – a demonstration project as showcase

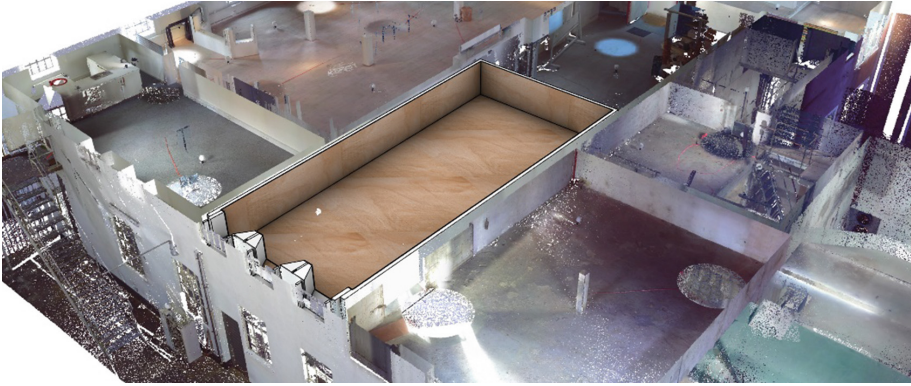
The Aarhus School of Architecture entered into a partnership with the Municipality Faaborg Midtfn, which is impacted by economic and demographic changes, to develop a method and conduct a pilot project.

Based on the above-described method, the Aarhus School of Architecture prepared a report containing a value assessment of the cultural heritage values and a 3D scan of the building. This report was used as the basis for a tendering process to find an Architectural office as a collaborative partner and the lead architects on the project. This Architectural office and the Aarhus School of Architecture as research partner developed the demonstration project collaboratively.

#### 3.1 Building Transformation

After the initial assessment of the building and the context, a transformation strategy, primarily based on internal reconstruction, was decided. The transformation concept has its point of departure in a house-in-house principle (Fig. 4), meaning that independent structures containing the apartments are to be built inside the existing factory spaces. The decisive arguments for this strategy are built on the idea of circular economy and the adaptive reuse of historic buildings. A key factor for this strategy is the concept of design for disassembly, which has become the design premises for the development of the demonstration project. This concept is tailored towards the overall

realm of adaptive reuse of architectural heritage, which leaves the possibility to disassemble the entire project at the end of its lifecycle, or whenever a more lucrative business model should arise, without major damage to the building.



**Fig. 4.** Transformational concept “house-in-house”

Five new apartments are constructed of standard off-the-shelf materials and build in a rigid modular grid. This grid is not adapting to the actual outline of the existing spaces, but it follows its own rigid logic.

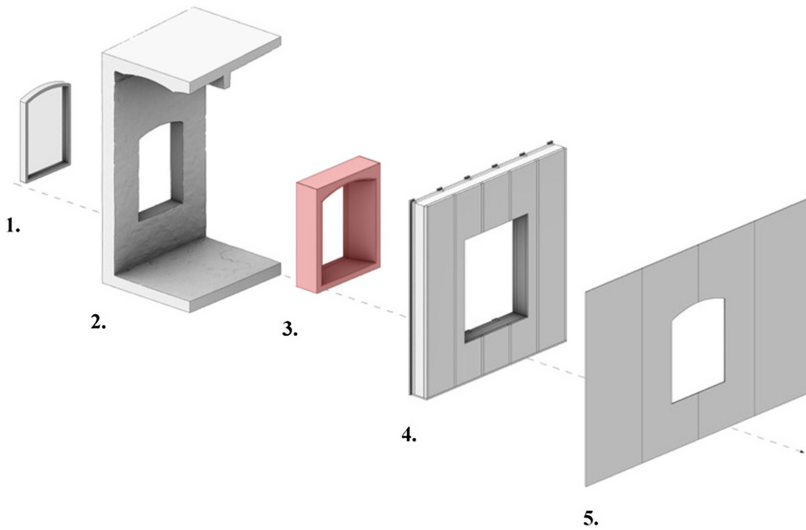
As a response to the concept of design for disassembly, these structures, which are forming the new apartments, are positioned in the existing industrial spaces. They are detached from the existing walls and constructed entirely out of standardized timber and plywood sheets of the shelf. The build-up of those new walls has to meet all the required codes according to insulation and indoor climate but does not need to constitute a complete climate screen. In continuation of the overall idea of circularity, a wood fiber insulation material has been chosen for the new apartments.

## 4 The Module

Due to a transformational concept, based on the superimposition of a rigid modular grid on top of an irregular historic building complex, bespoke modules were necessary for adapting to the new structure to the existing building around windows and doors. Those modules needed to adapt to the existing building on the outside and fit into the standardized system of the new structures on the inside. The reason why digital technology and digital fabrication is necessary in this case is the fact, that many of the modules are built around and connected to the historic arched windows of the factory building. Those arches necessarily have to be extended as ruled surfaces towards the inside of the building. Even though this task also could be performed by a skilled craftsman, economically this would not be sustainable, taking the amount of window modules into account. In manufacturing ruled surfaces can be achieved by e.g. wire cutting such as

hotwire cutting or abrasive wire cutting, but ruled surfaces can also be achieved by single curved bending of sheet material such as plywood.

A series of prototypes have been designed and fabricated. Both to test different material approaches, as well as different manufacturing concepts. The first range of prototypes was based on one solid homogeneous material and they are to be cut with an abrasive wire mounted on a 6-axis robot. The second range of prototypes was based on plywood sheets and CNC cutting as well as wood fiber insulation (Fig. 5).

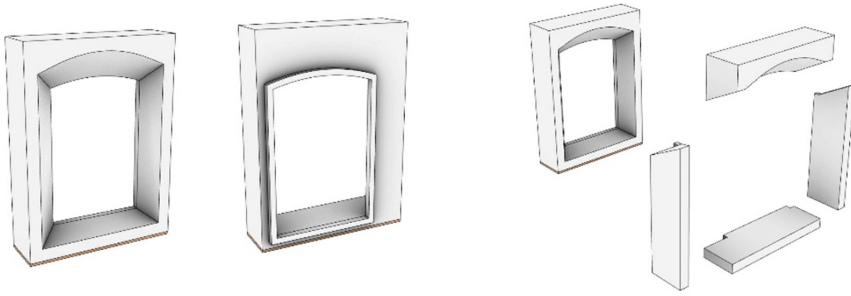


**Fig. 5.** 1. New window, 2. 3D scan of existing wall, 3. Bespoke Chalk/EPS module, 4. New woodfiber backwall, 5. New internal cladding

#### 4.1 Prototype 1 and 2

The first prototype of the bespoke module was designed for the manufacturing of an experimental material, which is based on a mixture of chalk and EPS. The main concept for this material is to combine a local high-quality building material (chalk) with a waste product from the industry (EPS) to form a new material with increased material properties and architectural quality. Because of the homogeneous character of the material, it is suitable to be cut into a desired shape through robotic fabrication.

The insulation capacity of the cut modules, due to the EPS aggregate in the material is sufficient to fulfill the requirements according to heat loss. At the same time, the material is vapor permeable and the surfaces are reflecting the sunlight beautifully due to the chalk. A major disadvantage of this material showed to be the high weight. Solid modules, broken down into four pieces as shown in Fig. 6, would weight too much to be installed on-site by construction workers.



**Fig. 6.** Chalk/EPS module based on ruled surfaces ready for robotic fabrication

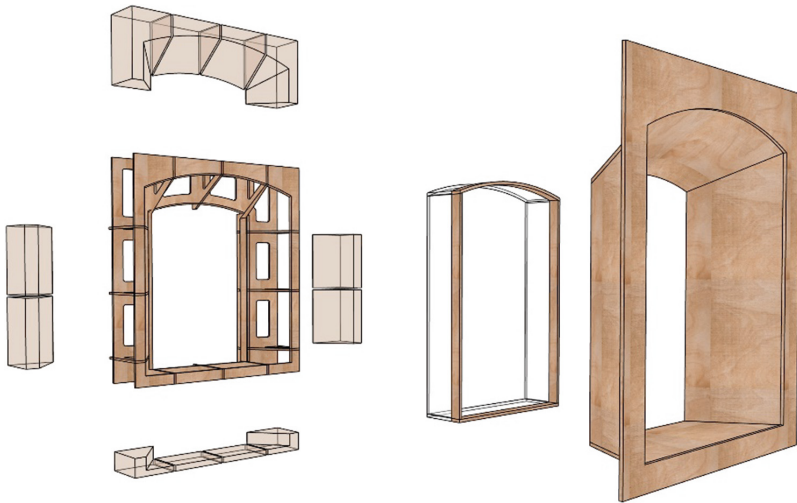
Consequently, the second iteration of prototypes was based on a material with a lower weight but still with homogeneity and integrated insulation capacity. The chosen material was aerated concrete block used as standard masonry block in the industry. This material has the same advantages in terms of manufacturing.

#### 4.2 Prototype 3+4

The second range of prototypes was purely based on timber products and designed to meet the demands of design-for-disassembly. The design is based on 3- to 5-axis CNC milling in plywood sheets. A design pipeline, with the 3D point cloud scan as input and the CNC-cut files as output has been established to rationalize the manufacturing of all the different window types. The modules are designed as waffle structures, which reduces the weight significantly and allows for insulation with wood fiber batts (Figs. 7 and 8).



**Fig. 7.** Modules prototype 1 and wood-fiber back wall mockup



**Fig. 8.** Plywood module broken down into pieces ready for CNC fabrication

## 5 Summary

To summarize, the laser scanning and cultural heritage value assessment allow detailed design decisions at an early stage as well as precise implementation. The modular strategy helps to increase the reversibility. Besides the advantages in terms of precision and automation, the application of digital technology and digital transformation also opened up for implementation of complex geometric shapes, which would have been difficult otherwise. The digital workflow links all project phases together and opens for a differentiated material implementation based on specific material performances and the production of bespoke building modules.

The demands to the specific digital workflow and demands for a certain precision narrow down the range of realization strategies to a very specific approach in terms of manufacturing of parts, but also allows for a certain flexibility in the design both in terms of materiality and detailing.

## References

- Hansen, J.Z., Stephensen, P., Kristensen, J.B.: Modeling household formation and housing demand in Denmark. DREAM, Danish Rational Economic Agents Model, Copenhagen, pp. 115–122 (2013)
- Proshanky, H.M., Fabian, A., Kaminoff, F., Kaminoff, R.: Place-identity: physical world socialisation of the self. *J. Environ. Psychol.* **3**, 57–83 (1983)
- Jokilehto, J.: A History of Architectural Conservation, pp. 115–118. Routledge, London (1999)
- Randall, M.: Assessing values in conservation planning: methodological issues and choices. In: de la Torre, M. (ed.) *Assessing the Values of Cultural Heritage*. Research Report, pp. 5–30. The Getty Conservation Institute, Los Angeles (2002)

- Anker, M.L.: Kulturminnevern, skjønn og forutsiktbarhet: En Studie av offentlig arealplanlegging og bevaring av kulturminner, 2007:229, p. 35. Doktoravhandling ved NTNU, Trondheim (2007)
- Boulaassal, H., Chevrier, C., Landes, T.: From laser data to parametric models: towards an automatic method for building façade modelling. In: Ioannides, M., Fellner, D., Georgopoulos, A., Hadjimitsis, D.G. (eds.) *Digital Heritage. Lecture Notes in Computer Science*, pp. 42–55. Springer, Heidelberg (2010)
- Fai, S., Rafeiro, J.: Establishing an Appropriate Level of Detail (LoD) for a Building Information Model (BIM) - West Block, Parliament Hill, Ottawa, Canada. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **5**, 123–130 (2014)
- Kolarevic, B.: *Architecture in the Digital Age: Design and Manufacturing*, p. 31. Taylor & Francis, New York (2005)
- Lylykangas, K.: Energy-efficiency Upgrade with Prefabricated Façade Elements – the Innova Project Renovation Saturnuksenkatu 2. In: *Proceedings of 4th Nordic Passive House Conference*, Riihimäki, p. 8. Electronic Publication, Helsinki (2011)