Reverse architecture and digital twin in open standard for the transformation of heritage buildings

Pilot project: the Simplon-Orient-Express station in Vallorbe, Switzerland

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Abstract

Heritage buildings linked to important infrastructural projects present a specific set of architectural design challenges for their conservation and reuse. While storing valuable forms of cultural knowledge, they are not yet encompassed within current debates and methods on Building Information Modeling (BIM), their complex geometry defies standard forms of 3-D representation, and the planning documentation over their life-span has frequently been neglected or overlooked. The functional capacity of, for example, railway stations, must also be maintained at the same time as ongoing social and technological transformation takes place within their regional, national and international contexts. This paper argues for a combination of different digital tools in the documentation, maintenance and transformation of heritage buildings, and discusses in detail the innovative, pioneering methods of constructing a "digital twin" of the Vallorbe railway station in Switzerland, built in 1913 to accommodate the Istanbul- London Orient Express. Designed to accompany successive phases of the building's life-span, such digital models themselves can become long-term conservers of architectural history. Rather than an automatic process, digital twin construction requires a particular set of architectural skills, representing a new form of digital craftsmanship, which, when using open formats, can guarantee a sustainable, transnational transmission of planning practices.

Keywords

transnationalism, digital planning method, reverse architecture, digital twin, transformation simulations, national monument, Simplon-Orient-Express, Swiss Federal Railways, Building Information Modeling (BIM), data preservation, point clouds, open standard IFC.

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Fig. 1. Taillens Dubois architectes, drawing of the Vallorbe Station, 1911.

THE VALLORBE STATION, A NATIONAL MONUMENT ON THE SIMPLON-ORIENT-EXPRESS LINE

Although the Alps cover around 60% of the surface, Switzerland boasts the world's densest railway network. Many parts of this comprehensive infrastructure also comprise important cultural heritage of European railway history, linking technology, building culture and public space. At the end of the 19th century, the international interests of Switzerland and neighbouring countries were focused on establishing a rail link from the North Sea to the Mediterranean across the Alps. Two tunnels were built: the Gotthard, completed 1881 and the Simplon between Brig and Domodossola, completed in 1906, which was the longest tunnel worldwide until 1982. Subsequently a direct route for the Orient-Express between Paris and Venice was sought. Instead of passing through Geneva, a shorter route through the Jura mountains with a new tunnel under the Mont-d'Or was decided on. As there were no major cities to host proper railway facilities in this peripheral location on the French side, both the Swiss and French railway companies jointly planned and realised a complex for their employees and the travellers, including customs buildings on the Swiss side[1] above Vallorbe- a town of around 4300 residents.The mountainous topography linked to the important new railway infrastructure required massive earthworks of 600 000m^3, one of the country's most significant.

The federal authorities aspired to an architecturally representative building in order to demonstrate the arrival in Switzerland directly after the Mont d'Or tunnel, in particular to the British gentry on their journey to the Orient. The station was designed by architects Taillens-Dubois[2] in Heimatstil, with local features deriving from Art Nouveau and known as Style Sapin [see Fig. 1]. Smaller stations in this style can be found in Sonneberg, Germany, Starý Smokovec, Slovakia or La Baule-Les Pins, France. Major works in Style Sapin are the crematorium by Belli, Robert and L'Eplattenier as well as the Villa Fallet by Janneret and Chapallaz, both in La Chaux-de-Fonds, Switzerland. However a building of this scale (5000m^2) in Heimatstil with its sculptural roof-shape, paintings on the façade and natural stone, was rare, signalling an impressive building solidly rooted in local architectural tradition.

As the Vallorbe Station had to be built on the slope of the mountain, stones excavated from the tunnel were used to build the foundations of the main building. But the slope was so steep that a second basement level had to be built. The architects planned a single basement only and never drew this level. Probably because of the lack of a plan, this remarkable level -2 in between the raw stones from the tunnel, has never been used [see Fig 6b, plan produced within this pilot project (with fictive design)].

From its completion in 1913 until World War II, the Vallorbe station received international royalty and many important travellers. However after the war, several changes led to a decrease in activity and reduced the prestige of the Vallorbe Station site. The electrification of the line made the operators redundant. The abandonment of this Orient-Express route in 1977 erased Vallorbe from the international traveller's map and the change of customs procedures made the two dedicated buildings vacant. Throughout this slow decommissioning, no accurate documentation of the complex was carried out; the sections and facades from the construction date of 1911 and the architectural plans from the 1950's.

POINT CLOUDS AND DIGITAL PLANNING METHODS FOR CONSERVATION

The Vallorbe station exemplifies the complex problematic of historical buildings of high cultural value located within transforming social, cultural and technological contexts. For this reason it has been chosen as the case-study under discussion- a BIM pilot project commissioned by the Swiss Federal Railways (SBB). Digital planning methods can offer long term solutions for the preservation of heritage stored within these cultural reservoirs. Such buildings need constant maintenance and upgrading to meet new technological requirements. Infrastructural changes must be accommodated and exploration of the spatial potential is important to understand how architectural transformations can be most effectively planned according to their historic value. Frequently, no complete set of drawings of the buildings exist. Under these conditions, we argue that three dimensional scanning of the building is an invaluable tool for the creation of transferrable documentation.

In addition, digitalisation itself creates further long term challenges. The transferability of data is hindered by the domination of different software companies meaning that valuable data can easily be lost. Such data is also a form of heritage that deserves to be preserved. To address this issue we propose the exclusive use of data in open formats.

Historic monuments, in particular related to infrastructure such as trains stations, undergo a cycle of one to two deep transformations per century, for example the electrification of the train tracks at the beginning of the twentieth century and currently the centralization of the track commands– first requiring the construction of command posts and signal boxes, and today their dismantlement. A digital model delivering accurate plans of the building is of great advantage throughout these transformations.

As no up-to-date documentation of the Vallorbe Station was available to build an accurate digital model, three dimensional scanning was carried out. This scanning involved photo- and laser-grammetry from which two products were derived: 3D meshes and point clouds[3]. Point cloud is a format frequently used in archeological documentation, where the existing structures are particularly sensitive or cannot be touched.[4] It rapidly captures all objects that define space with the accurate precision required by the architect, however the procedure requires external specialists..In this case geomatic engineers scanned the facade and 60% of the interior of the building. The point density of the cloud is about 1 point / cm^2 and they are georeferenced in accordance to the Swiss reference system LV95[5]. The building has a surface of 5'000m^2 and a volume of 16'000m^3, resulting in 60 GB of structured point clouds to be used by the architect to build an accurate three dimensional model. Point clouds are highly precise but not directly exploitable for planning as they are almost unreadable in two dimensions and are not parametric entities, meaning they do not contain parameters that can be modified. Parametric entities are necessary in order to simulate transformations– that is to design, therefore the information from the point clouds has to be manually integrated into the digital model.

As the site's morphology is complex, 3D topographic meshes were used as reference for the terrain. But this topographical model must be remodelled for two reasons: firstly, the Lidar based mesh is also non parametric and can therefore not be modified. Secondly, the representation of topography with a Lidar mesh is not comparable to contour lines and is not readable in a plan view [cp Fig. 2A (mesh in 3D) and 6b (contours in 3D)].

One constraint for the planner is that for the production and development of digital models, CAD software requires its own coordinate origin and not that of the georeferenced data. The precision will otherwise be reduced and the calculation for 3D visualisation and movements will be increased by the large numbers of the coordinates.

The georeference however to be kept as the point clouds are imported in the CAD software and reintegrated in the model during the IFC publication procedure.

Georeferenced IFC allows planners to link all models spatially and a building owner such as SBB, to locate one object within a lager model that will contain all of their assets. Eventually the architect's models could complete the GIS model from the public authorities[7].

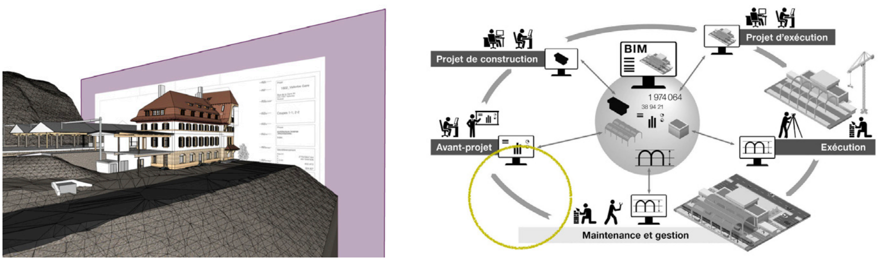

Fig. 2. A – Algorithmic extraction of a drawing – here a cross section – from the Vallorbe Station model. B – The five phases of the BIM method (from left, clockwise): 1. Preliminary design, 2. Construction design, 3. Execution project, 4. Execution, 5. Maintenance and facility management. The current projet explores data reuse between phase 5 and 1 (circled). The average time span of the loop is estimated to 50 years[6]. Note: the loop for the technical infrastructure can be completed in less than half the time. ing of the Vallorbe Station, 1911.

REVERSE ARCHITECTURE AND DIGITAL TWIN

Reverse architecture – a term used by R.L. Krikhaar in computer science[8]– refers here to studying an object to determine how it functions or how it is made. The principle is based on the collection of three dimensional scans of the object's surface. In addition to the point clouds, the architect will supplement his knowledge of the building with models of the terrain, archival plans, photographs, descriptions and any other document that can provide him with relevant information on the object to be "retro-designed". The product of this reverse architecture is a digital architectural model comprising geometric and alphanumeric data (descriptions in numbers and words).

The production of a parametric architectural model is carried out by systematically placing objects (e.g. walls, slabs, windows) in space using the point cloud as a reference [Fig. 4a: section through the building complex point clouds and digital models]. Currently some software, with artificial intelligence techniques, eases the making of digital model in the point clouds but it has not yet been automatized. Algorithms that recognise shapes within point clouds and insert pre-fabricated objects from a database at the right position exist in laboratories[9] and may be offered as tool on the market for the production of models within a decade. Nevertheless for historic buildings, the realisation of a data base containing historic objects (e.g. doors, bathtubs, convection heater from all centuries) does not make sense as almost all objects are unique and made by artisans.

Therefore the reverse architecture process, or in other words, the production of a digital model of historic buildings, will remain a step-by-step manual task for qualified people This virtual reconstruction of a building is a task requiring care and knowledge– a new kind of craftsmanship. It could be argued that this process represents a paradigm shift in architectural planning. In their research on "Media Agency", Barlieb and Gasperoni in fact present a case for the seamless merging of analogue and digital medien in the design process as potentially generating a radically new type of architectural thinking.[10]

A digital model of architecture alone cannot reveal all the knowledge contained in a historic building– models from civil engineers, mechanical, electrical, and plumbing engineering are also required. Within the lifespan of a building the technical infrastructure undergoes constant development –the service life of these items is about half of the building renovation cycle, which means that changes in this model will theoretically occur twice as frequuently as in the architectural model [see Fig. 2b]..

Following the production of the architecture model, an important task was to link a small library of 16 digital objects to be found in almost every train station – the ticket machine, the famous Hans Hilfiker design clock–to and an existing alphanumerical database of these items. An average station has hundreds of objects and each of them are recorded in a database that contains detailed information on, for example, the production factory, the date, the installation company, or the object warranty. All information on all objects would not fit in a digital model, therefore a second model was produced containing only these objects, using the architecture model as template, and linking them to the databank.

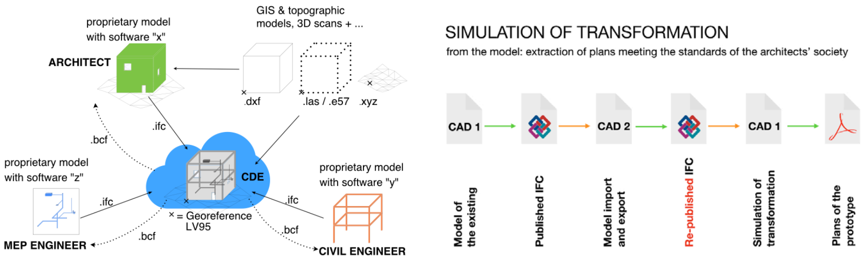

Fig. 3. A – Diagram for the production of plans after multiple reuses of the IFC by different software. B– Schema of the Vallorbe station digital twin in a CDE based on open standards.

Through this pilot project, the authors realized that to be more accurate, several models and types of data were required; the complementary geometric and alphanumerical information could not be integrated within the architectural or engineers models as they where in different digital formats or too substantial, for example the Geographic Information System (GIS) models, the point clouds from the geomaticians or the alphanumerical information related to the railways infrastructure.

Together, these different files represent the Vallorbe station, but in order to have a comprehensive “image” of the station, the files must be connected. This was achieved through severals links: the files were placed within a Common Data Environment (CDE), geometrical information were linked through identical georeferencing and alphanumerical data was linked to the model through objects identification numbers.

This ensemble of linked files within the Common Data Environment represents the “digital twin” of the station-

a term “digital twin” used by A. Pilling [Op.Cit.]. The entire set of data constituting the building is then the Digital twin for the Vallorbe Station [Fig. 3b].

DIGITAL DARK AGE VERSUS DATAS IN OPEN FORMATS

In today’s digital age, transnational exchange in everyday planning practice is dominated by a handful of multinational software companies. These companies deeply influence our planning methods regardless of the regional specificities of the built environment. The pressure to progress and the business competition forces architectural practices to upgrade their software almost every year.

This constant and rapid development of software, also linked to hardware development, has both advantages and disadvantages;. software development makes extremely powerful tools available to small and medium-sized companies, constituting most of the architectural and engineering firms in Europe); these tools are now capable of processing huge amounts of data on a standard personal computer[11] to model entire building complexes. Within two decades the method of producing plans has been revolutionized[12]: today architects no longer draw all plans but can extract them from the models using algorithms. [Fig. 2a]. The disadvantages are the obsolescence of these tools and the risk of digital dark age[13], where historic information becomes lost due to either the hardware or the software being no longer available.

One way of avoiding this obsolescence is by using open source software and open formats that respond to ISO standards. For the building industry and the BIM digital planning method, the open format is IFC, Industry Foundation Classes (ISO 16739). The institution that develops this format and delivers certifications for it, is buildingSMART; originally this international organisation was called International Alliance for Interoperability (IAI, 1994-2005)[14]. BuildingSMART is an important international platform for the exchange of ideas, technology and methods aiming at sustainable solutions. However to date, historic buildings have not been prioritized. While the international transfer of data using open standards is an important objective, the next generation of architects will be primarily confronted with the transformation of existing buildings.

This paper addresses this cultural-technological gap in architectural practice by pioneering the innovative use of digital models and open formats in the documentation and transformation of historical buildings.The current state of the art allows architects and engineers to produce digital models of buildings in open format IFC for almost all planning phases: design, construction plans and management. However the potential reuse of this format two or three decades after the building has been realized for a major transformation is still little understood. The authors argue that this lack of knowledge is due to the fact that the real uses of this format started less than two decades ago and buildings built with the BIM method are still too recent to be transformed.

For example a LOD 200 model for preliminary design of an historic industrial complex produced in 2002 with a CAD (computer aided design) software can no longer be used because the operating system no longer runs. Today, such a model can therefore neither be reused nor read. However, most of the model's geometry can be recuperated if published in the open format IFC 2[15] -it will be possible to extract plans that respond to architectural norms (see Bibliography), and is not linked to specific software.

The Vallorbe Station pilot project is between two planning phases: the phase of facility management when the building is in use, and the preliminary-draft for a major transformation of the building, when the digital model used for the first design will be reused [circled on Fig. 2b] to simulate the spatial and structural changes to occur within the building. At the completion of the works, the model can be used for facility management until the next transformation.

The authors argue that, the condition of reuse of the digital models between two long cycles of substantial transformations (see Fig. 2b) is to produce a digital twin in open formats. The next part describes in detail how this method was executed in the Vallorbe station pilot project.

Fig. 4. A – Representations of the digital twin. Left, section through: topographic model, point cloud –geomaticians– SBB infrastructure model –engineers–, architect model existing (black) and transformed (red) e.g. allowing access to people with reduced mobility. B – Architect's view of the transformation. Beyond the graphic aspect, the building's geometry is represented with 1cm tolerance and the shadow projection is exact (21.09.17/12:00).

SIMULATION OF TRANSFORMATION

Through the process outlined above, the digital twin containing following set of files on the Vallorbe train station was created. Ideally the digital twin should live a parallel life to the building: during the building maintenance, small updates should be performed with a simple tool[16] on the open format model. After 20-50 years [4/5 of the BIM cycle. See Fig. 2b] the open format model should be re-imported in a CAD software to simulate a major transformation of the building.

An important objective of the pilot project was to understand how the geometry and the basic information can be retrieved from the model in open format– still be readable in 20 years– in order to plan a major transformation of the building.

Today building models are often archived in formats determined by the software; any later modifications of these digital models are then carried out with the software from the architect or the engineer that produced them, restricting further use and transferability. However in this project, the open format model could be reused to produce architectural drawings that meet current standards independently from the software.

Unlike mainstream contemporary architecture produced with the BIM method, many historic buildings of cultural significance have a complex geometry. In the case of the Vallorbe Station the exact shape of the gambrel roofs above the two aisles and crossed by the one from the main central structure, had to be conserved in the open format IFC in Boundary representation (B-REP). This formality allows the representation of a complex 3D shape by defining the limits of its volume. It will then conserve the exact shape of the parametric model used for the simulation of transformation such as in the Vallorbe station, the geometry of the monumental swing stairs from the central hall including the cast iron banister [see Fig. 6a]

The objects requiring transformation can be processed according to different operations that all buildingSMART certified CAD softwares should be able to perform. This process begins with basic vectorial corrections and ends with the production of new 3D parametric objects.

Finally, in the pilot project the architectural model with the fictive design could be used to publish plans and sections on the scale of 1/250 and on the scale of 1/50 with a few graphic mistakes [Fig. 5a & b].

In many other countries, an oversized station for a village such as Vallorbe would have been sold in a procedure of investment reduction by the owner. The Swiss government has instructed the state-owned company SBB to make their property assets profitable, therefore they are seeking solutions for the future of the Vallorbe Station after the infrastructure for the railroad switches will be dismantled. Currently the building hosts several apartments and a restaurant that should remain.

The idea of a station as a destination in itself, rather than a walk-through building -has again become relevant for a station such as Vallorbe in the 21st century. Today, its international status depends only on the stop of the Lausanne-Paris high-speed train, which could be lost if this train passes through Geneva. It is therefore a station as a destination in itself that has guided the design of the transformation.

A historic example of a destination station was the one of Pavlovsk Park on the outskirts of St. Petersburg in the 19th century. The engineer who initiated the project proposed an amusement park at the end of the line in order to attract passengers. It included a restaurant, reception rooms, a promenade, and galleries in a garden. The “musical railway station”, as R.Dayanov[17] called it, linking the two functions of train station and concert hall within a pleasure garden, was an innovative idea and a resounding success. This pleasure garden was based on the model of London’s Vauxhall (whose design was noticed by gardener and witter John Evelyn in 1661[18]) dedicated to the emerging gentry. Within the Vauxhall compound, carefully-designed gardens surrounded concert halls and music pavilions – an idea that rapidly became fashionable, resulting in the construction of several further examples all around Europe[19].

During the Vallorbe station pilot project several scenarios of transformations have been developed. The current trends in terms of mobility have been studied by the SBB and the most suitable for an decentral and small area, such as this village, has been chosen. The station square, currently used for traffic, is liberated for socio-cultural activities.

The design for the transformation integrated several cultural and recreational programmes; an exhibition area in the majestic hall from the time of the Simplon-Orient-Express; a cine-club and an oriental bath, between the remarkable stones of the Mont-d’Or tunnel from the forgotten basement as well as a small hotel under the roof and in the rooms left empty by the obsolete infrastructure.

These proposals supplement the lack of cultural, leisure and touristic facilities in the town of 4000 inhabitants, which have slowly been closed down parallel to the steady population decline of around 16%; the only cinema closed in the 1970’s and there is only one small hotel.

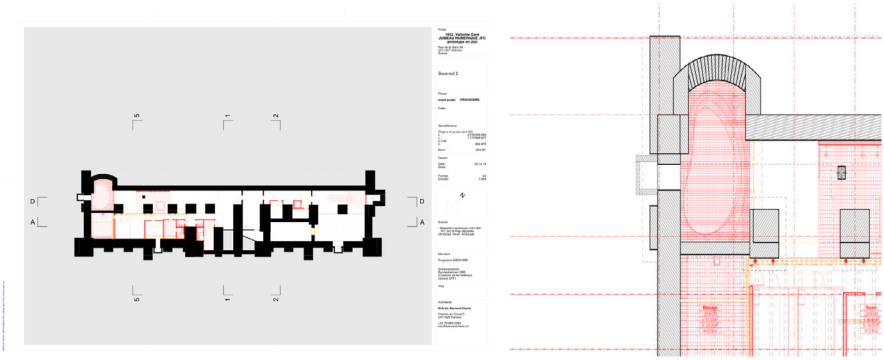

Fig. 5. A – Plan at scale 1/250 extracted from the model in LOD 200. B– Detail of a plan at scale 1/50 extracted from the model in LOD 300 showing the need of improvement by software developer: the wall was fragmented in IFC to reproduce its geometry, as the fragments are not associative they disrupt the graphic of the wall. The graphics of both plans is in accordance with the Swiss standard SN SIA 500 400.

CONCLUSION, THE OPEN FORMAT IFC FOR A CONTINUOUS RE-USE AND DOCUMENTATION

In continental Europe, architects and engineers work as independent practitioners to realise medium-sized building complexes. CAD is specific to the different professions: architects civil engineers and mechanical electrical or plumbing engineers[20]. The proposed transformation of Vallorbe station also represents a planning culture where the architect is commissioned directly by the building owner, as well as engineers. The design of CAD software responds to this specific planning culture.

In the case of planning errors, a lawyer will be engaged to define the responsibility of each party engaged and divide the costs according to the responsibility of the planners. This costly procedure has consequences for the planner therefore he will pay great attention to the plans – now respectively the models – he produces. The use of the open format IFC to exchange models amongst stakeholders during the planning phase is therefore important.

In the Anglo-Saxon, American and Oceanic planning cultures, building firms that include architects and engineers working as interdisciplinary teams, frequently realise either serial balloon-frame or high-rise building types. For this purpose, CAD is made to fuse digital models amongst colleagues from different disciplines with as little data loss as possible. In this case interoperability with open format is less relevant.

The Vallorbe prototype has been created with a non-exhaustive series of digital tools from both the European and Anglo-Saxon planning cultures, using a method currently applied only for the planning of new buildings rather than transformations. There are major differences in the use of digital tools in the different planning cultures. These differences appeared especially in the processing of open format which is essential in this project and for data conservation.

Fig. 6. A – Federation of point cloud and architectural model after transformation: view in the majestic hall toward entrance with fictive information desk. Point clouds demonstrate the accuracy of the architectural model. B – Exploded isometric of the design: the precision of the point cloud allows exact modelling and highly precise transformations simulations to the benefit of conservation.

The exchange of ideas and practices are intertwined. Ideas need practices in order to be implemented and practices need ideas to demonstrate their pertinence. Building plans are an important source of knowledge[21] that should be preserved. In the digital era as plans are extracted from the model, the model itself becomes the source of knowledge and it's conservation becomes of equal significance. Therefore only open formats such as IFC can guarantee a sustainable, transnational transmission of planning practices.

The prototype of the Vallorbe Station Digital Twin showed the possible continuous re-use and therefore the feasibility of a digital twin that has a parallel life to the building. For historic monuments with complex geometry, undergoing two major transformations per century, such a digital twin represents a great advantage for the planners, the building owner and other actors. The possibility to navigate through a virtual project is an important communication tool amongst users and stakeholders.

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No potential conflict of interest was reported by the authors.

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– "Vallorbe Gare, Prototype de Jumeau Numérique –Architecture inverse & opneBIM-transformation–". Documentation of the eponymous SBB pilot project. B. Cherix, B. Mahoubi, 2020 (Unpublished)
Note: developers and software's names are available on request at <info@bernardcherix.ch>
– Computer Aided Design (CAD) software
G*** A*** / A*** R***
- IFC analytical software
N*** S***
– IFC Viewer
N*** S***, A*** U***
– Local CDE including model and point cloud viewer
K** B**
– Web based collaborative platform (or common data environment, CDE)
A** B**, C** B**