BIM as a tool for reuse

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Introduction of the current context

"The European construction sector alone accounts for nearly 50% of the consumption of natural resources and nearly 40% of the waste generation throughout Europe." [translated from French] [7]

The environmental situation is becoming more and more alarming, and the construction sector is greatly involved in it. It is responsible for a large part of the world's energy and raw material consumption, which has been increasing sharply for several decades. The world's resources are strongly decreasing, their extraction generates three-quarters of the energy consumption and CO_2 production of the whole construction. [28]
In response to the alarming situation, states have set targets for carbon neutrality by 2050, but according to the organization *Climate Action Tracker* the targets seem increasingly unattainable. [36]
The growing needs related to the demographic explosion, the real-estate pressures, and the use of poor-quality materials, favor the obsolescence of buildings which have a shorter and shorter life span.
The development and the economic model of the construction industry require reconsiderations and need solutions to slow down its frenetic activity.

Reuse is one of the practices which has a strong potential, allowing a recirculation of available resources in the building stock. [16] In Switzerland, 3.5 billion tons of materials could be extracted from the existing constructions. [29] Its application would allow to extend the use of the material with a low environmental impact. The materials of a building would be reintroduced in the construction, which would extend their life cycle and avoid them to become waste while they still have a strong potential of use.
The general interest of the sector is growing, but its application is still not widespread and difficult to apply, due to many technical, economic, methodological, and cultural issues. [7]

Within the framework of this Enoncé Théorique, the brakes on reuse will be a starting point to identify solutions and understand whether BIM tools, a widely used process that allows a gain in productivity during the design and construction process of a building, could provide a new dynamic to promote reuse. The role that the architect can take in this process and how he can use BIM process will also be one of the angles of reflection.

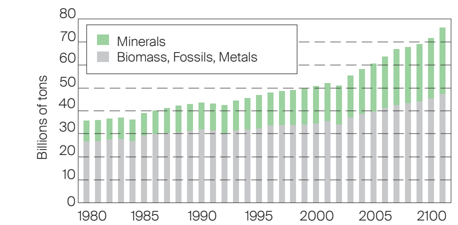


Fig. 1: Evolution of raw material extraction between 1980 and 2013.

[7] C. Dautremont, C. Dagnalie, and S. Jancart. 2018. "Le BIM6D Comme Levier Pour Une Architecture Circulaire."

[28] W. R. Stahel. 1981. "Jobs for Tomorrow: The Potential for Substituting Manpower for Energy."

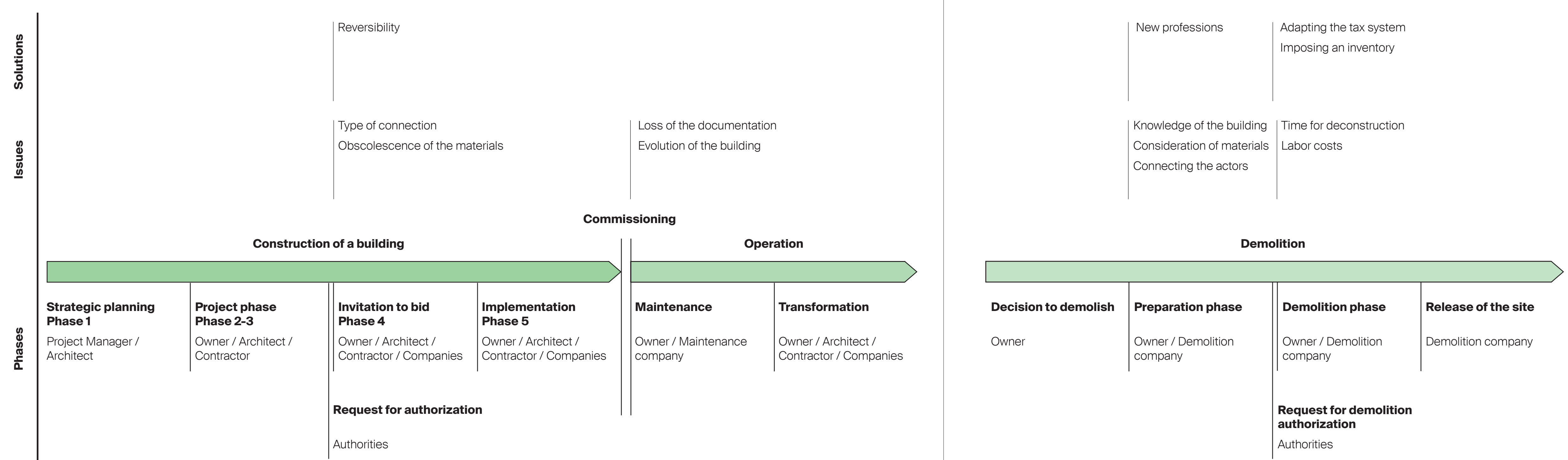
[36] "Climat : un seul pays sur 195 a respecté les promesses de l'Accord de Paris."

[16] J. Brütting. 2018. "Reuse in Architecture and Structural Design."

[29] Y. Huet. 2022. "Economie Circulaire et Construction." Arv asr Recyclage matériaux construction Suisse.

Reuse in the construction sector

The timeline below shows the different stages that materials have within a building and their change to new cycles for other project. The stages in the building process are the ones defined by the *SIA* (*Société suisse des Ingénieurs et Architectes*). The main issues and solutions that we will address are also indicated on the timeline.



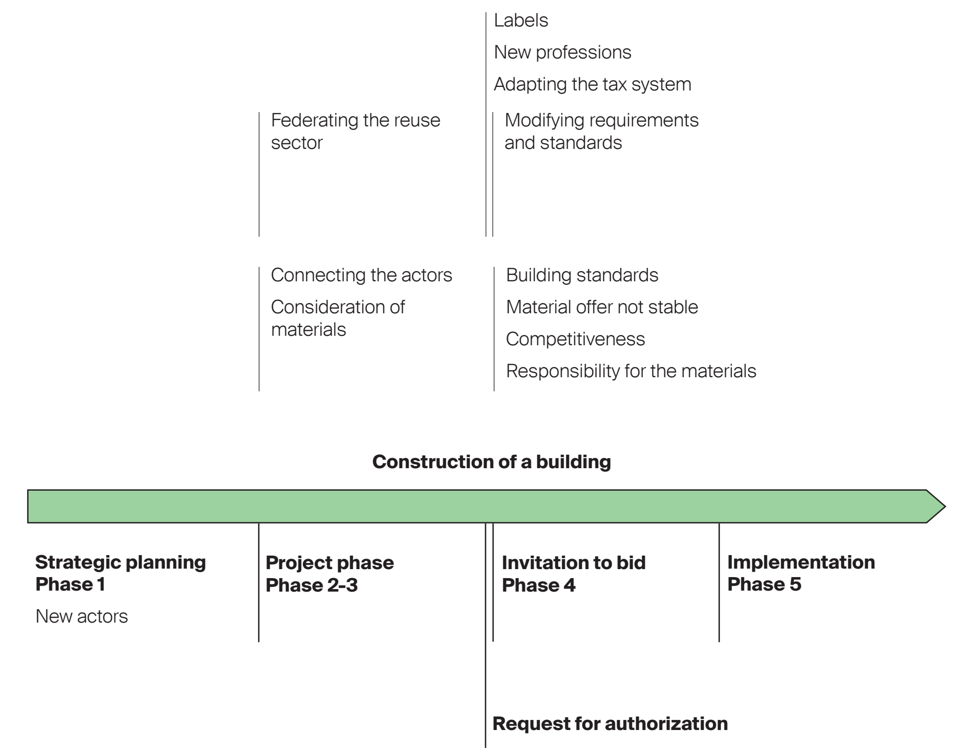


Fig. 2: Life cycles of a material in the building.

Realization of a project

Development and construction of a project
From the realization stage, the current construction methods presents important obstacles to the future reuse of materials. The sector is largely guided and constrained by financial objectives. During the construction of a building, the long-term vision is not privileged, which limits its capacities to evolve afterwards. [8]
The materials are assembled with connections that do not allow their reversibility, for reasons of saving time during assembly and reducing material costs. The technical elements such as water drains, electrical conduits are cast directly into the concrete, and the different materials are connected with increasingly resistant links (glue, mortar or others), forcing to change them to intervene on them or on what is behind.
The materials used also tend to decrease in quality, we observe a reduction of the material and their replacement by other less expensive, which leads to a reduction of their lifespan and makes the buildings becoming obsolete more quickly.

[8] C. Fivet and C. Küpfer. 2021. "Déconstruction Sélective, Construction Réversible."

Fig. 3: Architects Pollute; the impact of the architect's decisions on the environment.

The building faces a difficulty of adaptation, producing a very large amount of waste. [28] This waste is the consequence of a restricted vision that does not consider the evolution of the building, due to cost limitations during the elaboration of the constructive details. The architect is directly linked to this waste and has the opportunity to change the practices. Being at the heart of the design process, his role should also be to anticipate the evolution and deconstruction of a building.
Architecture needs to move towards a more responsible practice, using principles of spatial reversibility for a change of spaces and use of a building, as well as the reversibility of materials by guaranteeing mechanical independence between layers and allow their deconstruction for replacement and subsequent reuse. [4] The main objective of the sector must be to make the building last as long as possible.

[4] B. Känel. 2022. "Vers Une Construction Réversible Pragmatique."

Maintenance and transformation

a building must be able to adapt and evolve to best meet the needs during its operation. It is difficult to anticipate with precision its lifespan, because it is rare that it is planned for a fixed period. It can be used for several decades, or even centuries, or only a few years if it does not meet the needs.
Maintenance and modifications must therefore be considered. To be as relevant as possible, a maximum of documentation must be available to allow a good understanding of the building.
When commissioning, it is important that this documentation is as complete as possible and has been developed for use. In general, it is the role of the architect to prepare these elements and to transmit them to the project owner whom is required to keep them (plans, details, etc.) for at least 10 years in Switzerland.

This period does not cover the entire life of the building. The question of the conservation of the documents arises. In what form and how should it be maintained? Is the physical format still relevant with the development of digital technologies? Will we be able to use it in 20 or 30 years? However, the information must be accessible and must also evolve as interventions on the building take place, to remain as up-to-date as possible.

End of life of a building

Over time, the needs, and expectations towards a building change. Its reversibility may allow it to evolve, but inevitably its demolition will come one day. External factors could lead it to be replaced: real-estate pressures or urban reorganization. In Geneva, the district of PAV (Praille-Acacias-Vernets) characterizes well this urban mutation: almost all of the 140 hectares of this industrial area will be replaced by a majority of residential buildings.
In the past, constructions were not destroyed but methodically deconstructed so that the materials could returned to the building circuit. Compared to labor, they were more expensive and therefore financially more valuable and interesting.
At the end of the 19th century came the mechanical tools, which brought a considerable saving of time and upset the dynamics of deconstruction. In 1929, the *Majestic Hotel* in New York was a striking example: this luxurious establishment was demolished with a sledgehammer after only a few years, despite the presence of noble materials. The resale of the materials had been estimated equivalent of only 10% of the price of the deconstruction. [19]
Due to economic issues practices have changed.

[19] M. Ghyoot, L. Devlieger, L. Billiet, A. Warnier, and Rotor. 2018. Déconstruction et Réemploi, Comment Faire Circuler Les Éléments de Construction. Pressempolytechniques et universitaires romandes.

Fig. 4: Demolition of an apartment building in an upside-down manner.

The time dedicated to deconstruction has become very short, leaving no opportunity to deconstruct the elements. The reuse of materials requires more care and time and has given way to a summary management of waste: "[e]lements without known utility." [8]
Governments have also pushed for successive demolitions, with "a policy of encouraging the demolition of housing considered obsolete." [translated from French] [19] The consideration of the materials has therefore decreased and a loss of knowledge related to their implementation in building has occurred.

The policy on the recycling of materials has made it possible to take a first step backwards, by obliging the sorting of construction waste and thus avoiding its systematic dumping. This constraint has directly impacted demolition methods, pushing to sequence the interventions for the different parts of a building.
Governmental have had a significant and direct impact and can bring a change in practices. The policies in Switzerland are currently mainly oriented towards recycling and are only slightly interested in reuse. [6] Unlike it, recycling does not preserve the quality of materials, they must be reprocessed which consumes energy. [1]

[6] A. Thorens Goumaz (Conseillère aux Etats). 2022. "La Ville Circulaire + Planifier."

[1] A. Akbarnezhad, K.C.G. Ong, and L.R. Chandra. 2013. "Economic and Environmental Assessment of Deconstruction Strategies Using Building Information Modeling."

As the reuse market is not yet well developed, time constraints and the very high cost of labor compared to the price of new materials is a problem of competitiveness. Construction is a profit-making sector where the financial aspect remains the driving force. During the demolition stage of a building, the main actor is the demolition company, the architect rarely takes part. Could he find a place during the planning stage to promote reuse and make it more attractive and efficient with the help of new practices and tools such as BIM?
With the current context and environmental issues, reuse is becoming a more and more discussed topic. Many companies are starting to put it into practice and develop new processes. In Geneva the association *Mátériuum* is very active in the dismantling and resale of reused materials.

Matériuum

To understand their process and the different issues and challenges they face, I went to their premises, on chemin des Sports in Geneva. They have a storage and sale space where people can go and see some of the materials they store, like a flea market.

This non-profit association intervene essentially on buildings that are in the process of being demolished. The owners contact them directly to evaluate and sell they can. After an initial on-site survey

of potential materials, they list them in a catalog available online on their website.

If they find a buyer, only then, they return to the site to dismantle the elements. If no one is interested, nothing happens and the materials are left in the building and will be processed as a normal demolition, and probably becoming waste.

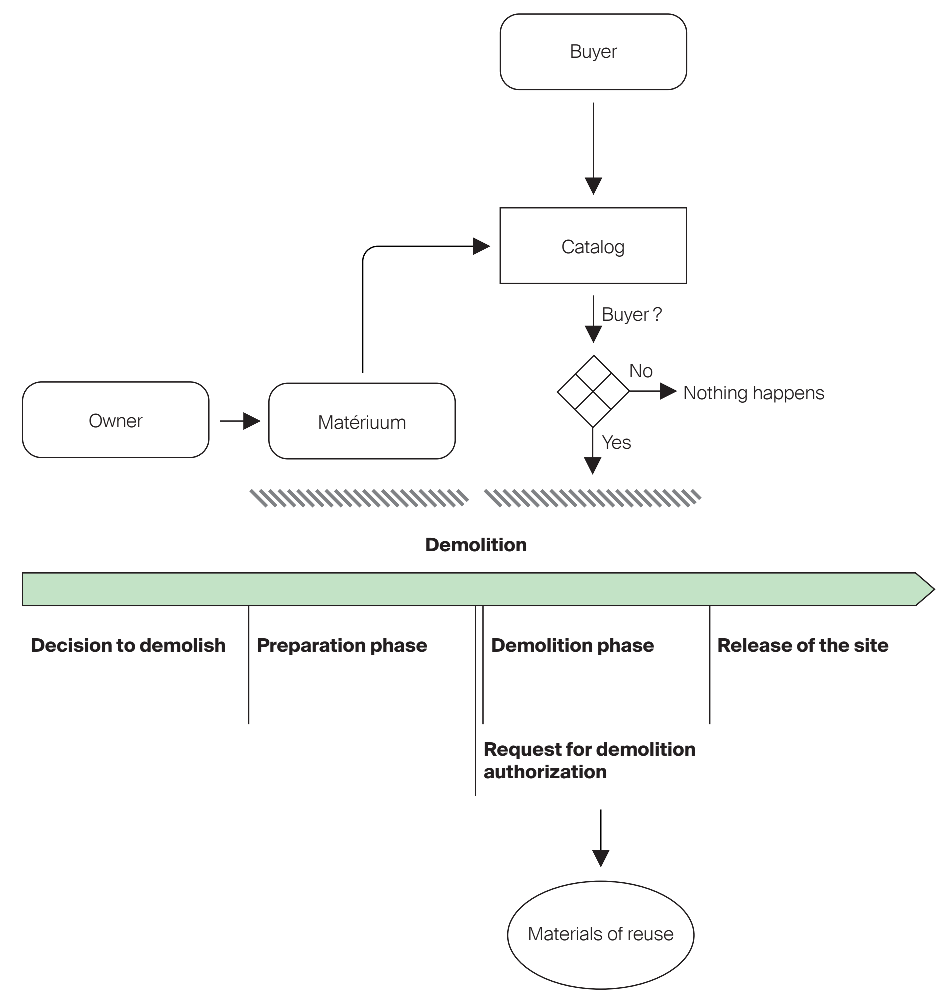


Fig. 5: Matériuum process: recirculation of materials.

Their action could be described as an opportunistic intervention. Their process is very strongly sensitive to the demand which is still low and very punctual. The buyers are mainly private actors or small companies that are looking for alternative ways to build, to detach themselves from the dynamics of consumption. Unfortunately, the majority of the professional sector does not turn to this kind of solution. [32]

[32] R. Bach. 2022. Visite des locaux de Matériuum.

Fig. 6: Reuse element for sale on the Matériuum catalog.

In addition to the low interest, they must remain competitive with new items. They mainly set prices according to the costs involved: labor, handling, cleaning, etc. However, they have difficulty in keeping the prices low and interesting.
The elements take time to disassemble, and treatments are sometimes necessary. Any additional step quickly increases the costs. Their offer is therefore mainly oriented towards the elements that could be described as "terminals", the elements directly accessible such as doors, sanitary appliances, panels. Elements requiring the dismantling of several materials to reach them generate additional costs.
With their process and the dynamics of the market, they can only have a limited vision and not on the whole building.
As the demand is not predictable, they cannot dismantle elements in advance and build up a stock, the financial risks being too important. Their offer is therefore impacted and becomes very punctual, depending on the opportunities they have. The availability of the elements is very short, depending on the time between their intervention on site and the demolition of the building in question, only a few months.

Development of reuse practices

Like *Matériuum*, other companies are also very active in the field of reuse. In Belgium processes are particularly well developed and have become part of society's customs. *Rotor* is one of the major companies which is very involved in the re-circulation of materials. They are also dynamic in research and development to make practices evolve. They gained an important notoriety thanks to their multiple interventions and involvement in European debates and events around the reuse topic. They have published books in which they share their principles and methods. Their discourse is starting to be heard and gain momentum in Europe. The awareness of the citizens is one of the first steps to change the mentality of the construction sector.

To give visibility to the actors and to connect the sector, different platforms are being developed. *Rotor* participates in the development of *Opalis*, which highlight companies who offer services related to reuse.

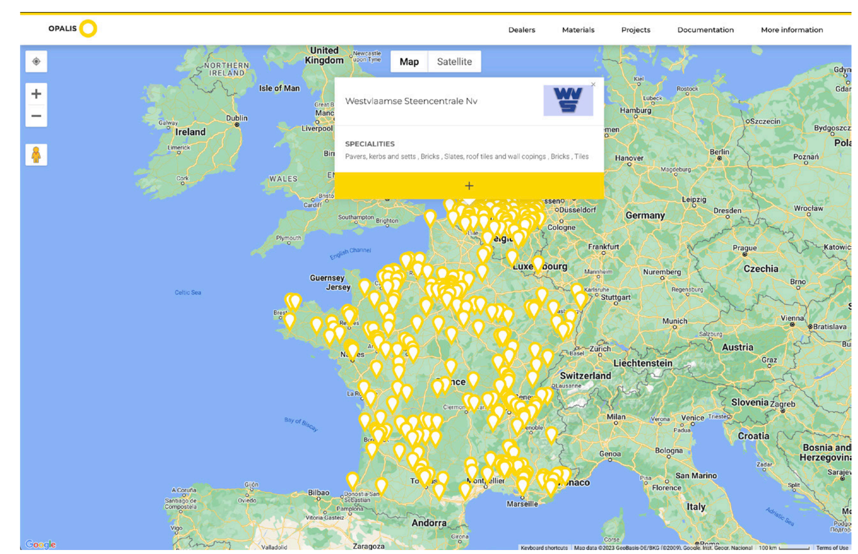


Fig. 7: Maps of the reuse actors available on Opalis.

There are also platforms that offer a database of available materials like *Madaster*. They offer the possibility to download BIM files linked to the data of the elements to facilitate their reintegration in future projects. [40]
These different approaches are not limited to the borders of a country, but seek to connect the sector on a wider scale. Reuse is a common challenge for the construction sector, for which each actor has a role to play. Although attitudes are beginning to change, the lack of motivation and stimulation remains a major problem. Society is focused on new elements with a constant need for evolution. Despite the great potential for using materials after being demolished, getting people to agree to buy elements that have already been used and may not last as long is still very difficult. [6] In other sectors, product recirculation is gaining

[40] "Madaster: The Cadastre for Materials and Products."

[6] L. Bottani-Dechaud (Rotor). 2022. "La Ville Circulaire + Planifier."

momentum, and construction should follow suit.

The valorization of the action must be a driving force to answer the lack of motivation. Labels can be used to highlight utilizations made and governments can have a more direct impact since they are the ones with the greatest influence. Different methods can be set up to incite or impose an advance for reuse.
The requirements for the use of materials could be relaxed for reuse elements. Changing their status would allow more flexibility. The tax system could be adapted for the different services related to reuse: labor, reseller; and, thus, make them more attractive and competitive. Belgium has already adapted the VAT for activities related to the reuse of materials from 20% to 6%. In Switzerland the VAT is 7,7% except for the basic necessities, the activities of reuse could be also redefined and submitted to a lower taxation.
Minimum deconstruction or reuse rates for permit applications could also be defined. The CO_2 impact could be a source of highlighting the efforts provided and benefits could be attributed, whether financial or focused on other types of assistance: prioritization of the file or provision of storage space (another issue when reselling materials).

For several years, Seattle, in the United States of America, the State has required that an inventory of materials during demolition and offer financial compensation for each ton of waste avoided must be made. If materials will be resold, companies are also allowed to start the deconstruction before obtaining the permit and a list of companies taking back these materials is made available to them. [42] Thus, this obligation has forced to develop different benefits and services to promote and enhance reuse. They developed the first tools to plan a deconstruction in a methodical way.
In Switzerland, the city of Basel is also starting to have a mandatory identification of construction waste.

[42] "Residential Deconstruction - SDCI | Seattle.Gov."

The implementation of these solutions could require additional work in the planning stage, which would be strongly linked to the knowledge of the building. The existing documentation would be of great interest and would serve as a basis to make these tasks more precise and efficient.

Baubüro in situ

The Swiss architectural office *Baubüro* in situ is strongly involved in the reintegration of reused materials in their projects. They intervene after the stage in which *Matériuum* does. To understand the issues and how they are implementing reuse, we will take their Hall 118 project in Winterthur as an example.

This project is an elevation of an industrial building. The steel structure and the various materials used come from the reuse sector. With this pilot project they have succeeded in making the reuse approach operational. Throughout the development, they searched for materials to reintegrate into the project. The lack of visibility and the almost non-existent market made the task time and energy consuming.

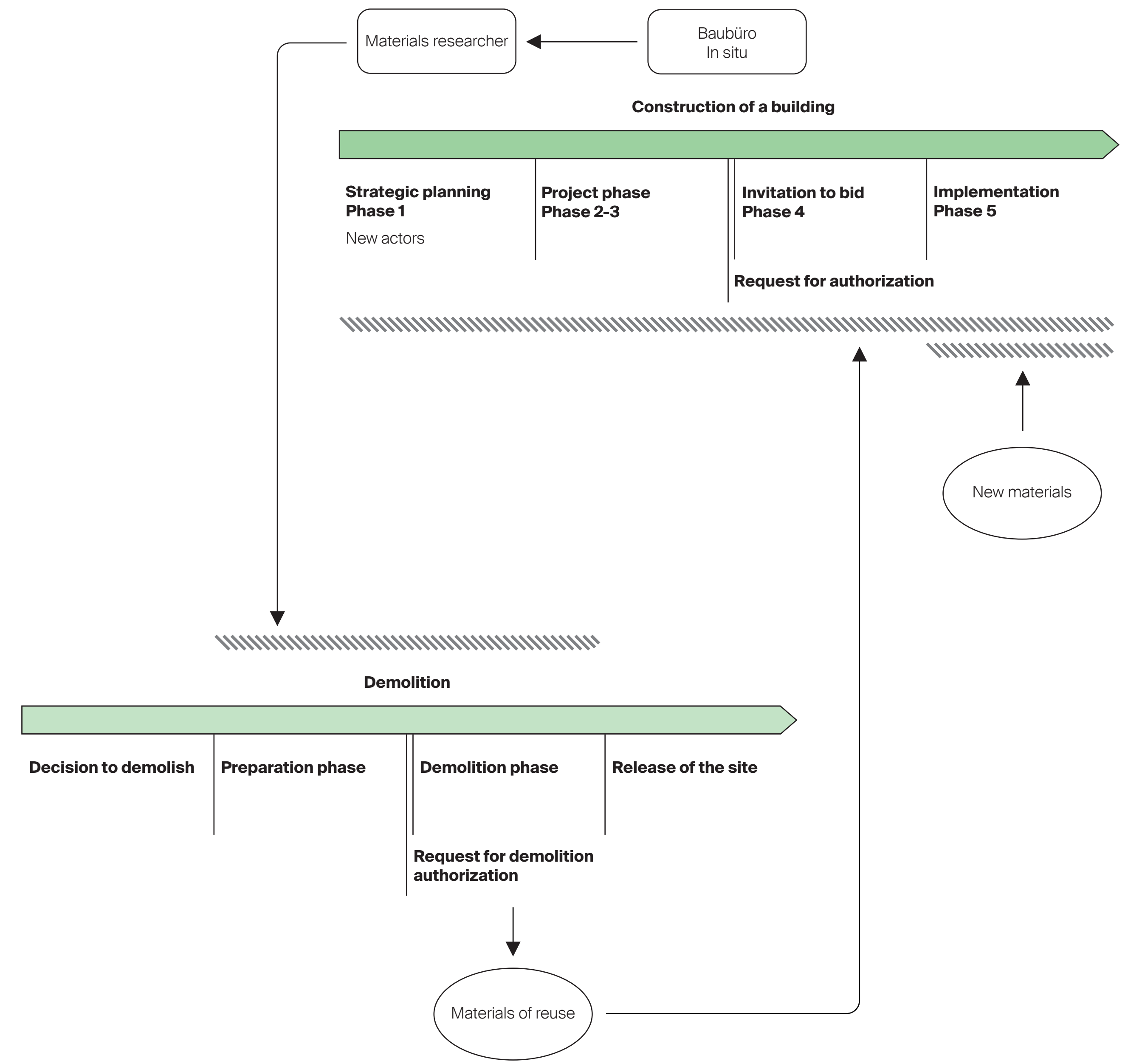


Fig. 8: Baubüro in situ process: research and reintegration of reused materials in a new project.

To integrate them into the project they had to be very flexible and adaptable even after the building permits had been granted, and used constantly dynamic processes to do so. [11] Changes

[11] E. Wegerhoff. 2022. "Baubüro in Situ Chez Transa: Une Esthétique de l'inachevé."

Fig. 9: Halle 118, by Baubüro InSitu.

in a project at an advanced stage can become complicated and generate a lot of work and cost.
BIM tools can facilitate this kind of modifications and make them possible without generating additional errors.
The construction companies, as well as the authorities, also had to show some flexibility since the details and materials were not all defined, they could still change until the last moment.

During their conference at the Forum: *La Ville Circulaire*, in Lausanne, [6] *Baubüro* presented two ways of conceiving reuse in a project. The "radical" method where the objectives of reuse are very clear from the beginning, and as long as the materials have not been found the project is not built, which can delay the project. The second method, "opportunistic", also intensively looks for materials to reintegrate, but an alternative of new elements is possible if nothing is available.
Their example project sets aside some of the issues of reuse, thanks to the impulses and will of the different parties involved, which does not make their methodology directly applicable to all projects. They opened the door to reuse and showed the enormous potential it can have for architectural project. The question and the choice of materials are fully put in the hands of the architect.

[6] E. Honegger (Baubüro In situ). 2022. "La Ville Circulaire + Planifier."

BIM as a tool for reuse

BIM, Building Information Modeling, is a process of work with a digital model. It is the "vector of the digitization of the building" (Bernard Cache, EPFL Professor) [17] allowing a gain in productivity and a reduction of errors, thanks to the central place taken by the collaboration between the professions. [19] [7]
This methodology is implemented with to various tools [3] such as Solibri, Simapro, Naviswork, or Revit which allow to develop various aspects of a project: thermal simulations, lighting, planning, cost calculation, quantity surveying, modeling, etc.
The advantages brought by the elaboration and maintenance of a building take an increasingly important place in the construction sector. Would BIM be suitable and successful in providing solutions to issues that limit the reuse of materials?

[17] K. Corazza, M. Jammers. 2022. "Lettre Ouverte – Préservation Des Enseignements BIM,"

[3] Acca Software. "Fichier IFC."

Build with BIM process

During the development of a BIM project, the architect is the first person to work with the digital model of the building. Throughout the process, he builds it and makes it evolve to be as close as possible to what the building will look like. It is sometimes referred as its digital "twin" [2].
BIM goes beyond geometrical modeling. It allows the project to be put into data, with the addition of different levels of information called dimensions. The first ones are the most known which are the point for the first dimension, the plane for the second dimension and the third dimension is the volume space. The fourth dimension (4D) is time management and the 5D the economic management of the project. Subsequently, these data can be extracted and exploited to meet the different needs and aspects of the project. [39] The number of dimensions is defined by the number of uses of the data that can be made with the BIM which could be extended if the needs evolve.
The different elements of a model are not only 3D objects, they are also characterized by their own properties. This notion of data marks the difference between BIM tools and CAD (Computer Aided Design) tools such as Autocad or Sketchup.

[2] A. Faivre. 2020. "Le Numérique Vecteur de Réemploi."

[39] "Les dimensions du BIM : 3D, 4D, 5D, 6D, 7D, 8D, 9D, 10D."

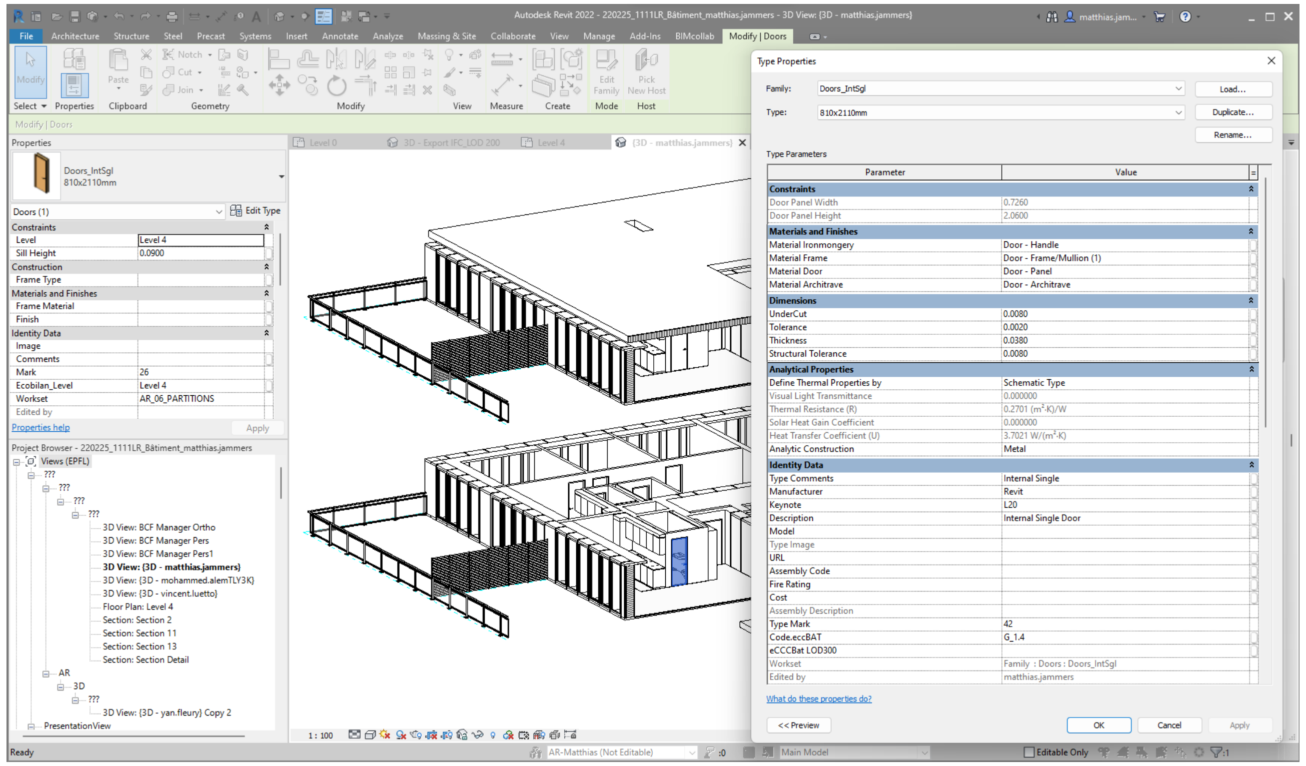


Fig. 10: Informations in a door type in Revit.

The BIM images, are taken from a work of a student in master of architecture at EPFL, developed during the BIM teaching unit in 2022.

The rehabilitation of this parking lot into housing, had been divided into two teams, one on Archicad (floors 3 and 5) and the second on Revit (floors 4 and 6). To allow the coordination of the two groups on the same project, various BIM processes were implemented.

For the model to be fully exploitable, it must be developed as a building that would be constructed with a correct superposition of layers, connections between elements must be respected, etc. The modeling is pushed to a higher level of detail in an early step which has the benefit of allowing the anticipation of many of the problems that may arise later: collision between elements (the opening of a door blocked by technical elements) , technical duct closed before the installation of all the techniques, additional estimates following the omission of certain elements, etc.
Working with a model makes the visualization and understanding of the building easier, more precise and efficient. It is the basis of the production of various documents such as plans, sections, visuals, quantities, quantity takeoff. They are directly linked to the model and are therefore automatically updated. Updating and exporting deliverables (plans, details, quantities and metrics) following modifications are very fast and greatly facilitated compared to CAD methods. More traditional methods require more effort when changes are made, all documents must be modified individually which can lead to errors and changes are limited from a certain project phase.

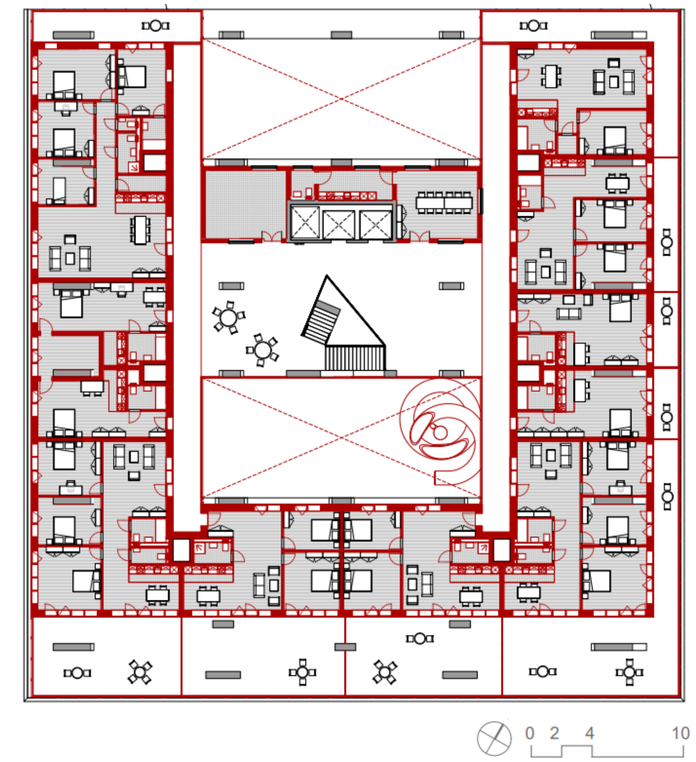


Fig. 11: Plan of the 4th floor extracted from the digital model from Revit.

Once the model has been digitally built it becomes an exchange basis for the collaboration with the various contractors. It centralizes all the information of the project and allows its exploitation thanks to various BIM tools. From the same model, all types of simulation can be performed: thermal, lighting, etc.
To be as accurate as possible and directly linked to the real conditions of the site, each object has x y z coordinates that are defined in relation to a geographical position. This is called geo-referencing. The goal is to generate various scenarios to establish the most suitable strategies for the site and project needs. [14]

Many trades intervene in the project during the collaboration. They do not necessarily need all the data. To optimize exchanges and facilitate the work, filtered exports of the model are made according to the different needs.
Working with a common model allows a dynamic process during which the various stakeholders can give impetus to the project and make its development less linear. [22] The earlier the decisions are made in a project, the less financial impact it will have.
This study shows the decision making of a workflow with BIM and one without BIM according to the evolution of the project. The earlier decisions are made, the freer the design development and the project management is from economic pressures.

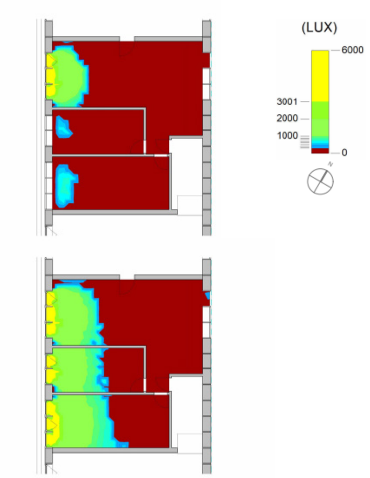


Fig. 12: Comparison of daylighting simulation of an apartment with and without opening, from Open Studio.

[14] F. Jalaei and A. Jrade. 2014. "An Automated BIM Model to Conceptually Design, Analyze, Simulate, and Assess Sustainable Building Projects."

[22] R. Vouilloz. 2021. "La 4D Dans Le BIM, La Mise En Données Du Temps."

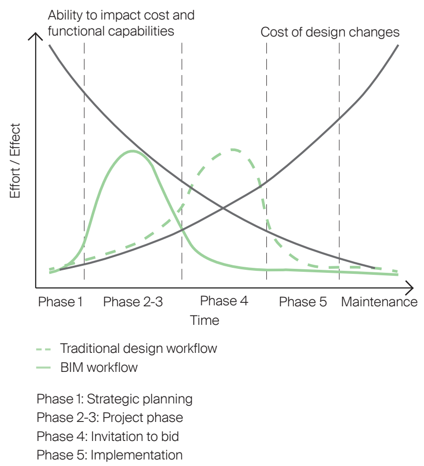


Fig. 13: Comparison of the impact of BIM and traditional workflow on the project.

To enable a common understanding of BIM and good collaboration, it is necessary to define use cases and a roadmap to guide users through the BIM process. [34] The development of these use cases is defined by organizations like the international organization for interoperability: *BuildingSMART*. Governments can also give help to lead the sector towards BIM tools, as is currently the case in Great Britain.

The BIM processes allow the use of different tools depending on the needs. To guarantee a good interoperability between them a standardized export format has been created readable by all and helps not to lose information during the exchanges. Since those techniques are new, it is frequent that data are lost during the export. This format is called the IFC (Industry Foundation Classes) format.

The use of this standard is a very important component of BIM. It ensures the use of a common and understandable language for different software. [13] It makes the workflows open, called open source, and is not governed by the use of a specific software that is called OPEN BIM. [3]
However, this interoperability does not fully reflect the dynamics of the BIM sector. Companies like *Autodesk*, one of the largest editors of design software such as AutoCAD and Revit, is holding back this opening and is trying to have the monopoly and exclude operating systems such as MacOS. This has already been the case with their dwg format which has overtaken the open source dxf format of CAD software.
Currently, Revit, their BIM modeling software for architects and engineers, has difficulty using IFCs on import and export and lags compared to other tools. For those software, we talk about CLOSE BIM, the workflow is closed on itself and allows only with difficulty exchanges with other tools, except for the ones developed within the same company.
Locking oneself into such a workflow makes the methods and working files sensitive to the decisions of the tool's developers. In an interview, Bernard Cache explain the risk of the market becoming "captive" to editors. [35] Nevertheless, large institutions continue to base their workflow on closed BIM schemes. [30] The users of those tools are sensitive to the company's choices and situation: if it closes their services, then the documents would no longer be usable, if it decides to increase the price of subscriptions then what can the user do other than paying more?
Software upgrades are a prominent problem regularly affecting the industry. When changing the version of a tool, the models need to be converted which can led to a lot of losses and changes in the data. During the development of a project, it is preferred not to change the version of the software.
The implementation of OPEN BIM processes is hindered and governed by mainly financial and not technological issues.

[34] B. I. M. Community. n.d. "How Is BIM in Switzerland? | BIMCommunity."

[13] F. Diara and F. Rinaudo. 2020. "IFC Classification for FOSS HBIM: Open Issues and a Schema Proposal for Cultural Heritage Assets."

[35] "Bernard Cache : 'BIM : derrière la technologie, le risque stratégique d'un marché captif.'"

[30] M. Alem. 2022. L'enseignement du BIM.

IFC is a format organized by classes (categories of elements) in which the objects are defined by features and functions. Being a standard, the classes need to be fixed and therefore do not let the possibility to modify the general structure. This rigidity can become a constraint when using very specific elements that cannot be correctly classified, like some technical elements. [13] [20] The tools and needs for BIM evolve quickly, and the IFC format is regularly updated to allow the development of its structure in relation to new needs.
It is a fixed format, "for read and analysis" [37], not allowing direct modification. However, it ensures that the information is not altered during the collaboration, the objective is to not directly modify this IFC file which must be seen as a deliverable document at a given moment and certifies the information. On the other hand, it requires more back and forth between the participants for small modifications. In practice, for certain uses, elements are remodeled in the various software to allow a greater flexibility of work.

During the development of the project, the different professions will produce their own parts of the digital model: architectural model and technical models. They are exported separately in IFC format, and then compiled into one model that will become central. All the elements are in the same format and can be assembled with the geo-referencing. This avoids the need to reconvert files in different software and the loss of information.

[20] M. Spearpoint. 2003. "Integrating the IFC Building Product Model with Fire Zone Models."

[37] "Industry Foundation Classes (IFC)."

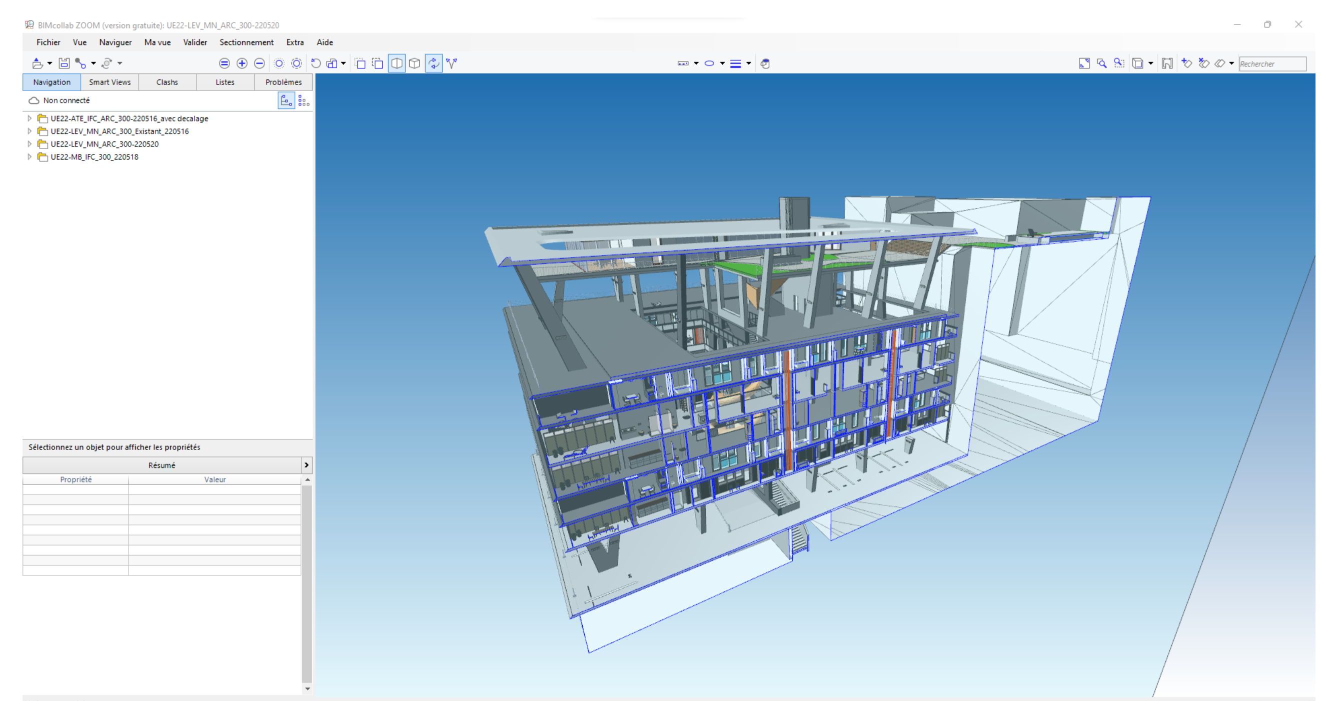


Fig. 14: Federated model of the different IFC parts of the project on BIMCollab.

This assembly allows to verify the coherence between the different parts of the project and to detect possible clashes between them. An anticipation and reduction of the errors can be made, avoiding a good number of the problems during the construction stage. During this coordination, a comment format called BCF (BIM Collaboration Format) permits modification requests to the different stakeholders. These comments can be directly visible in the modeling software thanks to plug-ins (software extensions that provide new functionalities). An interactive and dynamic collaboration is possible.

Fig. 15: Clash detection between IFC models on BIMCollab.

The collaboration requires working methods to be defined and framed with a BIM coordinator who will address the question of which software is used, the types of data being integrated, export methods, exchange platform, etc.
Depending on the size of the project, the architect is not necessarily responsible for this task. However, he must have a good understanding of the construction methods and be critical on the BIM practices to avoid an eventual restriction of the architectural development of the project. He must keep a freedom and not be penalized by the tools used. The architect needs BIM skills and being able to discuss the practices to be put in place with the coordinator.

The BIM allows an important gain of productivity by making the generation of documents fast and effective, thanks to an evolutionary model from which all the elements of rendering are drawn. The visual communication with the various participants is

privileged but this easy production can lead to a multiplication of documents requested, which can quickly become unnecessary.
To bring a real gain and for the architect with BIM tools and not be overwhelmed, the architect must put limits and define the necessary elements. The level of details and data in the model can also become a trap. It is easy to add information, but it must remain at the same level as the project progress. The concept of Level Of Development (LOD) has been defined to allow users to have a framework during a BIM project. It sets up different degrees that describe the graphical representation and alphanumeric information that the project's model must have. [5]
When developing a set of specification and defining requirements in the planning stage an LOD is established for all the stages of the project.

[5] BuildingSMART Switerland. n.d. "Définition Swiss BIM LOIN- (LOD) Compréhension."

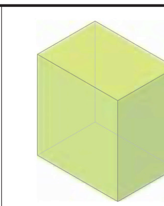
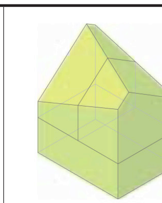
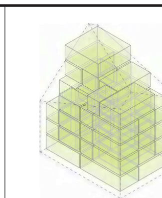
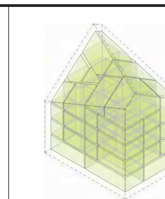
Space	100	200	300	400	500
LOG					
LOI	Building volumes	Partial volumes, building parts	Individual schematic spaces	Individual spaces	
Specific data	Type of object (SIA 112) SB/Building (SIA 416) Sectorization requirements	Use of parts of the building Type of use (SIA 2024) SP/SEP (SIA 416) Room height requirements Occupancy requirements HVACSE Requirements Acoustics requirements Lighting requirements Electrical/computer requirements Space Specific Requirements	Function/Type SUP /SUS / SD (SIA 416) Height of the rooms Nb of people Heating needs Air change rate Sound insulation measures Type and power of lighting Number of connections	Surface markingSlide hazard class Air/water/gas connections Circuit information Electrical/computer connections	Documentation
Manufacturer and product information					
Cost information	Costs of the object	Sector costs	Costs of premises and elements, not modelling	Component costs	Operating costs
Energy information	Needs and gains of the object	Sector needs and gains	Space needs and gains	Receipts	Operating data
Facility information	General operational requirements	Space number of the functional units Usage requirements Cleaning requirements Maintenance Requirements	Space number (planning)		Space number (operation) Functional unit numbers Maintenance information Occupancy information Access information Usage information

Fig. 16: Definition of the level of detail and information of the model according to different levels.

For example, it would be irrelevant to add information about the composition of a wall in the preliminary design phase. Like Lewis Caroll's 1:1 map that becomes as big as the land and no longer useful. [15] The level of detail should be related to the needs and should not always be pushed as far as it can be.

[15] G. Palsky. 1999. "Borges, Carrol et la carte au 1/1."

Glossary of BIM terms

The following glossary summarize the different BIM concepts that have been discussed previously or will be introduced later. Its objective is to quickly find the meaning of the terms used without having to search them in the text.

BCF BIM Collaboration Format, is a comment exchange format directly linked to the models, allowing to assign changes to be made at specific places of the project.

BuildingSMART International organization that seeks to improve practices and information exchange between BIM tools, who are at the base of the IFC format and who develop it.

CAD Computer Aided Design, includes all the drawing and modeling software oriented on the geometry of objects. The elements do not have internal data/properties like BIM.

Classification Way to structure the data in the model to allow users and software to extract it efficiently and accurately.

CLOSE BIM Work process where the participants use the same software or those of the same publisher unlike open bim. They do not need to change file formats when exchanging data, and become dependent on the tools.

Dimensions Layer of information and data intended for a specific type of use; 3D for geometric information, 4D for time management, 5D for cost management, etc.

IFC Industriy Foundation Classes, is a standardized file format for data exchange between software. It ensures a good interoperability and must guarantee the continuity of use in time.

Geo-referencing Geo-referencing: application of real geographic coordinates to objects. This allows the assembly of several models from the same reference points and apply the site conditions during the different simulations.

LOD Level Of Development, definition of the level of detail and information of the model according to different steps. It gives a framework to the users.

Native format Default recording format of a document proposed by the software. Once opened, the various elements have all the basic characteristics offered by the software unlike an imported format in which the elements do not offer all the possibilities of use.

OPEN BIM Open work process that implements tools and practices that ensure a common language and good interoperability between software. They must use standards and not apply native formats to software.

Parameter Category of information that can be added to an object. Subsequently, this data permits different types of exploitation: extraction, calculation, simulation.

Plug-ins Software extensions that add new functionality for specific needs. They can be created by the tool's developer or by independents.

Tools There are multiple BIM tools for different uses, here are some of them: Archicad, BlenderBIM, Revit for modeling; BIMCollab, Solibri, UsBIM.editor for collaboration on IFC format; Naviswork for planning and costing; Open studio for simulations; etc.

Workflow Process that defines the different steps, methods, and tools to be implemented for a given task and allows users to be guided and supervised. It ensures a good collaboration between several stakeholders.

Maintain and develop the building

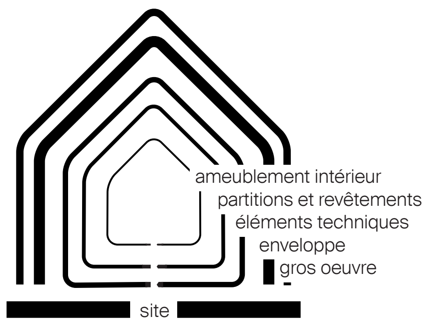


Fig. 17: The layers of a building according to Brand (1994).

The thickness of each is related to its life span.

The life of a building can last over several decades. During its exploitation, different maintenances are necessary to extend its use as well as the materials used. To allow a good management, the existing documentation is very important. It must give a precise understanding and identify quickly the areas and elements during interventions.
The BIM models centralize the information in a file avoiding the loss of certain elements and make it usable by any type of user. Those data have a great potential regarding the maintenance of buildings. It must be considered as a whole and the different layers that make it must be identified. The building does not remain fixed in time, and evolves in a non-homogeneous way according to different dynamics. Each of the layers encompasses several materials that have each been subjected to different constraints. Stewart Brand distinguishes six types of components in a building [8]: site – structure – skin – services – space plan – stuff; he uses those different layers to introduce the notion of a life cycle specific to each element.

Inevitably, after a while, the requirements and needs of a building are no longer the same. To remain relevant, renovations or transformations are to be considered.
The companies involved are no longer the ones who built and projected it and must therefore rely on the existing documentation available. The building imposes constraints and must be properly integrated into the project. The easier the documentation can be exploited, the greater the precision and the time saving are. During the development stage it is important to define the requirements of the model to use during the operation. It is necessary that the needs and the uses are well defined upstream.

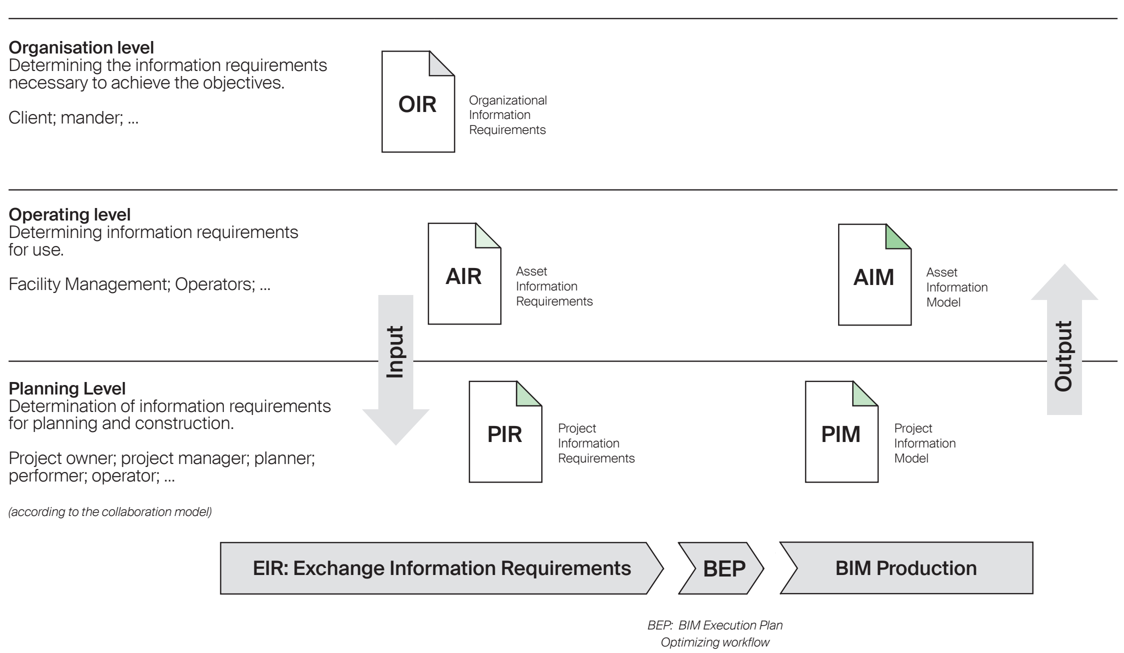


Fig. 18: Definition of requirements and their integration into a BIM model.

When a building is commissioned, the majority of BIM deliverables are in IFC format. Being a fixed format, the BIM model cannot be directly modified. To use it, it must be reintegrated into a modeling software. With the most used tools such as Revit and Archicad. When integrated, the IFC format is read as a single non-editable block. It is possible to model around it, so if existing elements need to be adapted a remodeling is necessary. They cannot translate the IFC back into an interpretable element with the same functionality and properties as native objects.
IFC is a format designed to contain a fixed model that does not permit it to evolve. However, for the monitoring of a building, the documentation should keep the data up to date, so it remains relevant to the building. While developing a building, the use of native workflows such as Revit is quite relevant, and leads to IFC exports for the deliverables. For operation, the documentation does not allow working with native elements, and it is then necessary to define the processes to be used. The question regarding the type of format used arises. With the most common tools, the standard format does not seem to meet the needs of the evolution of the building documentation over time.
The technology is evolving in line with the needs. In parallel to the main tools, software allowing modifications in the IFC format directly are being developed. UsBIM.editor allows to open the IFC format and interact directly with each element, while BlenderBIM is a modeling software using natively the IFC format so no export in a non-native format is necessary. The modification of an IFC does not lead to the loss of old information; a duplicate of the model is created, to browse the different versions afterwards. [30]
This type of software leads to a major rethinking of the functioning of other tools and their relationship to the IFC.

Briefly introduced earlier, the time dimension (4D) in BIM offers great potential when intervening on an existing building. The different elements can be assigned to phases the modeling stage. They allow to define different stages of construction or demolition. The basic tools include existing – demolished – new, but any other stage can be added.

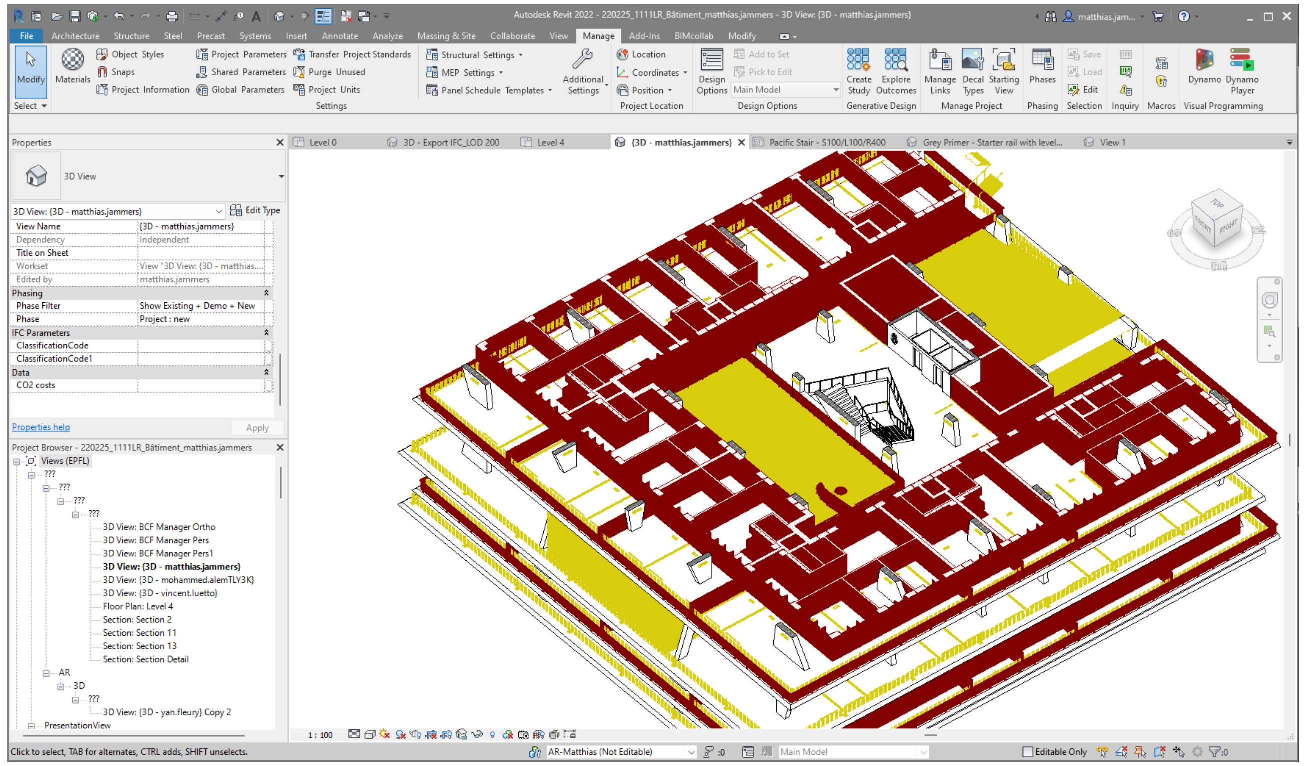


Fig. 19: Use of the different phases of construction and demolition on Revit. Colors according to Swiss standards.

This notion of phase is natively transferred in the IFC file on the export, allowing a good maintenance of the different stages of the building. Nevertheless, the demolished elements are not kept. This raise the problem of waste management or reuse of materials since it becomes impossible to exploit the data regarding these elements. They could still be exported with alternative methods by assigning them to a new, but still existing phase. With this technique, we would still have problems of clash detection between elements. The best would be to make an independent export for theses demolished elements but the main model would no longer be the centralization of all the data.
The IFC is oriented for the built part of a project at a given time. For the management of deconstruction for reuse, the format does not seem to be the most appropriate one.

Documentation is important to accompany the evolution of a building, but its storage represents a challenge on a time scale. Will it still be usable in 20 or 50 years? In the last 20 years there has been a such technological development that storage systems such as floppy disks and soon CDs, will no longer be used and usable.
Given the evolution of BIM and the place it is taking in the construction sector, we can assume that it will last for several decades at least. It is currently difficult to imagine that IT will disappear, except for extreme upheaval in society and rejection of

digital technology. In addition to guaranteeing the storage of the documentation, it must remain usable. The IFC format is designed to ensure the usability of the data in the future where the native formats of BIM tools will probably no longer be workable, either because the tools will have changed and will no longer exist or because their new version will have evolved so much that it will no longer allow the reading of old files. If in an extreme case, the methods evolve so much, one could possibly suppose that at a certain moment the information can be re-transcribed with the new formats and thus last.

The computer file storage can be done in two ways. The first one is on a hardware support like a hard drive, which would make the documentation only available on a specific element and would strongly limit its accessibility and represent a risk of losing data. The second possibility is to store it in a data center, making the model accessible at any time and remotely. One of the main criticisms of digital storage is linked to its ecological impact, very demanding in energy. In general, storage methods require specific conditions, and this is also the case for documents in paper format that need to be stored. A lot of space is required, as well as maintaining the right temperature and humidity conditions, which also represents a significant use of energy.
Despite the impact of storage, the conservation of data is intended to allow better management and use of buildings and materials which will have a favorable effect on the environmental impact of construction. Therefore, it needs to be stored and accessible.

Fig. 20: Data center.

Fig. 21: Document storage center.

To put the storage of a building's data into perspective, the documentation of a building can represent at most a few tens of gigabits (GB) of space. The *YouTube* platform, on the other hand, stores between 80 and 720 terabits (TB) (1 TB equals 1000 GB) of new videos per hour, and this mainly for recreational. [38] Given the disproportionate use and storage of this kind of platform, the data to maintain the data of the built seems quite acceptable.

[38] J. Pignol. 2017. "Chiffres YouTube – 2021."

Systematic deconstruction

During the deconstruction stage of a building, to promote the reintegration of materials, a different dynamic must be put in place combining the study and resale of materials, research, and reintegration into the project. To fully develop it in the construction sector, supply and demand must be sufficiently consistent. To increase the supply and detach it from the small scale it currently has, deconstruction materials should be deconstructed in a more systematic way and thus offer a wider choice for resale and in large quantities. Reaching 100% material recovery would be unrealistic and the effort required would be immense, but what can be saved should be saved. In the chapter on deconstruction, to see the potential of BIM and to reach dynamic discuss, some factors such as the standards, the lack of visibility of the actors or the capacities of the resale market will not be taken into account. These issues are independent of the architect and require external interventions. The objective is therefore to focus on one part of the material re-circulation process to see how it could be improved.

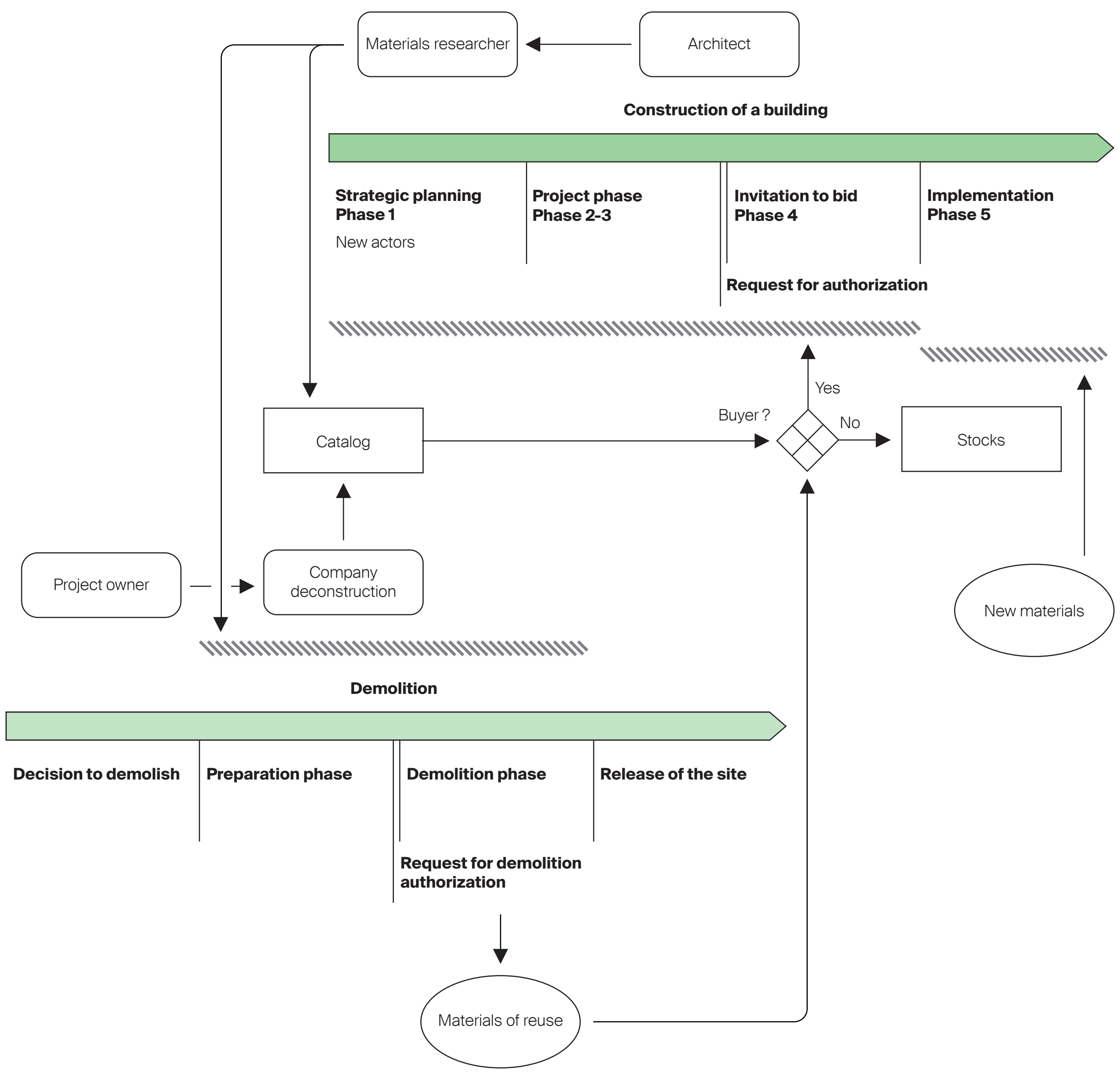


Fig. 22: Ideal process for recirculating materials.

During the deconstruction phase, the two mains challenges remain the time on site and the costs of the operation. It is necessary to optimize the methods and to plan upstream to gain

in efficiency in the construction phase. A first step of identification of the objectives would allow in a second step to define the deconstruction methods to be implemented. [27]
For a good planning, an understanding of the issues and objectives is important. The decision making and the costs involved will be strongly linked. Therefore, the building must be studied to intervene in a relevant way [10]. It must be considered as a whole and decomposed by layers. An "upside-down" demolition [19] must be avoided at all costs. Each layer can be seen as a system composed of several materials. For instance, in a wall, there is sub-structure, insulation, finishing layers, and each of them is held together by a connection: screw, glue, interlock, or other.

[27] V. Patraucean, I. Armeni, M. Nahangi, J. Yeung, I. Brilakis, and C. Haas. 2014. "State of Research in Automatic As-Built Modelling."

[10] E. Alby. 2006. "Élaboration d'une Méthodologie de Relevé d'objets Architecturaux Contribution Basée Sur La Combinaison de Techniques d'acquisition."

This junction has a big impact on the potential of reuse of materials when dismantling; a part could be saved while another could be destroyed. Understanding how the elements were implemented is fundamental. It is necessary to rely on as much information as possible to do so. A set of documents such as plans and details allow a punctual understanding according to the available elements while a digital model allows an understanding of the building as a whole. [24]

[24] T. Balodis. 2017. "Deconstruction and Design for Disassembly: Analyzing Building Material Salvage and Reuse."

The type of document available depends on when the building has been built. Today, projects are more and more developed with BIM tools, and therefore, in the future, BIM models will be available. Older buildings have generally no digital documents but physical elements (paper plans, etc.), if they still exist and have not suffered the vagaries of time: loss or damage.
When no BIM model is available, modeling one can represent a significant workload depending on the amount of documentation accessible. Upstream planning must allow process optimization and should not add too much effort, preventing the risk of becoming counterproductive and not being accepted by the sector. After deconstruction, the digital model will no longer represent an existing building and will therefore no longer be useful as such.
It is therefore important to estimate the needs and identify what BIM could bring in these cases. A partial model could be considered for certain parts of the building. The choice must be made case by case, depending on the objectives, the size of the building and the available documentation. The modeling of a building can still be relatively fast depending on the plans and details that exist.

In the situation where a model is accessible the model must have been kept up to date during its exploitation and its transformations for a good understanding of the building. The quality of the model is also important. If it has been used for a specific purpose and not for its full potential its exploitation could be difficult and would require additional work on it. When developing a construction project, it is important that the modeling practices are good and follow

precise requirements. The creation of data for future use depends on the work the architect has done on the model. In the use of BIM tools, the human factor remains very important The creation of data for a future exploitation depends largely on the work that the architect did. The sensitivity of the various participants has an impact on the parameters, quality of information and practices implemented. The architect must take responsibility for ensuring proper use of the data and allowing its reuse in future stages of the building. When using BIM documents, it is therefore important to first do a verification step, tools called Model Checker from the IFC, can help navigate in the model for this task.
The IFC format favors the storage of data, and allows its exploitation and extraction. If during its use modifications must be made, then its fixed aspect will require a re-translation in a modeling software to make changes possible. The current software does not allow this type of work with IFC and requires a remodeling. A non-negligible amount of work must be done, unless software like BlenderBIM which works directly int IFC format is used.
With the use of the model, the study of the different layers of the building allows an understanding of the interactions between the elements to identify deconstruction scenarios.
A research team from the University of Architecture in Brussels has introduced a new method of analysis which allows to identify the dismantling paths of materials in a building. Two factors are considered: the impact of connections on materials (percentage of loss and saving) and the dependencies between elements. For each scenario, an estimate time intervention can be made in relation to the connections to be disassembled. This method called: Disassemble Network Analysis and allows to identify the best deconstruction paths and to define the materials to be prioritized, according to several systems and their interaction and this at the entire building scale. [12]

[12] F. Denis, C. Vandervaeren, and N. De Temmerman. 2018. "Using Network Analysis and BIM to Quantify the Impact of Design for Disassembly."

This identification of deconstruction paths via scenarios could be integrated and calculated thanks to the BIM model. They are based on the types of connection, on the proximity of the elements and their functions. To do this, different information currently not filled in should be added to the different elements. A concept of connections should also be implemented to document the information that is its own: its resistance, the time of disassembly required, the percentage of losses in case of deconstruction, etc. This first identification of possibilities would allow to highlight the type of intervention considered and have a global view on the materials that could be extracted from the building.

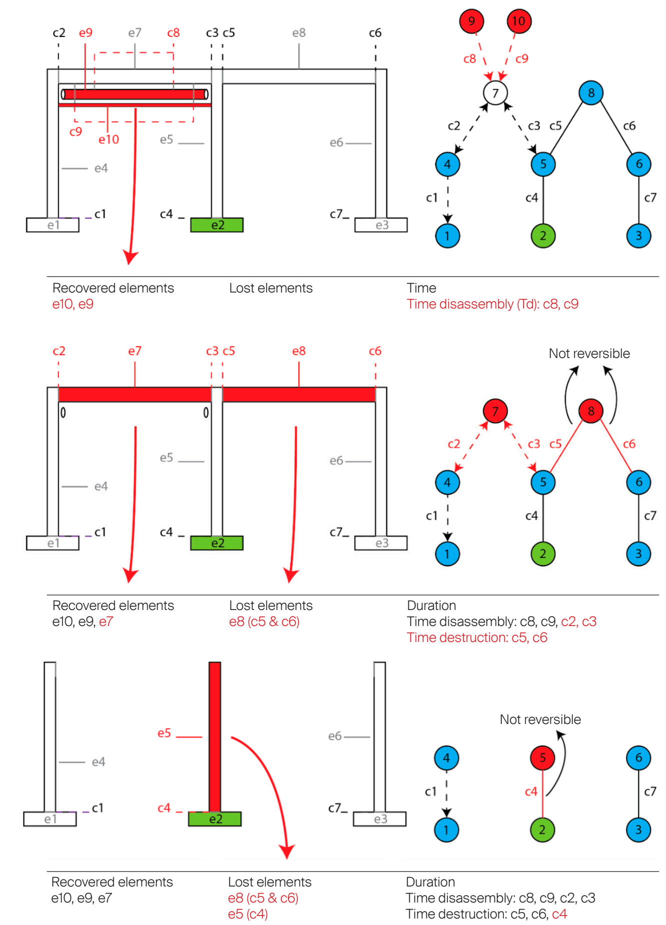


Fig. 23: The disassembly sequende (represented by the succession of illustrations above) to get targeted materials

The type of connection between elements is one of the major issues on the reversibility of materials. It greatly impacts the deconstruction methods to be implemented. Depending on the percentage of material loss the deconstruction of a system may not be a good solution. It may be more interesting to preserve it in whole or in part and reintroduce it as it.
The dismantling of a brick wall is a good example. The cements used for the connection between two bricks is becoming more and more resistant. It takes a lot of time to deconstruct and generates a large amount of waste. The reuse of bricks has become difficult and rarely exploited, although northern countries like Denmark, where bricks are a very common material, have developed processes to recirculate this material. [41] The *Resource Rows* project of the *Lendager Group* in Denmark uses whole blocks of brick to compose the facade walls, avoiding the dismantling brick by brick deconstruction of buildings. These blocks have been cut from an old system (wall) and keep their different layers.

[41] "Rebrick : Rebrick."

Fig. 24: Resource Rows, by Lendager group.

In addition to the scenarios and to identify deconstruction possibilities, specialized views are needed to bring observations and refine the choices. Collaboration with different stakeholders would allow a more detailed analysis and identification of potential problems to be considered. Each profession brings a different perspective and interest in reuse material. [7] [8] The model can take a central place in this collaboration by being the basis for understanding and discussion. To facilitate the involvement of trades less experienced with BIM, filtered exports of the model, oriented for the different stakeholders could be made, in which visual strategies would facilitate understanding and visualization. Color codes could be used to identify the functions of the elements or could mark the materials that will be recovered or not, the objective being to facilitate communication and collaboration. The architect could have a role on this planning and allow coordination between the actors. It is a job that is similar to the project and tender stages of a normal construction project. He has all the knowledge and capacities for this job.

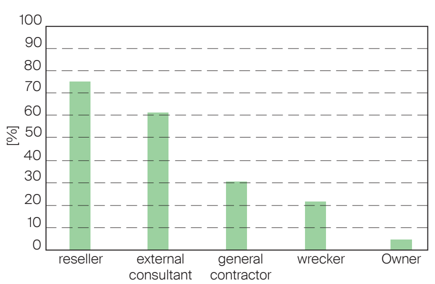


Fig. 25: Interest in reusing materials according to profiles. According to a study conducted in Seattle.

Working with an existing database is not enough. Even if it has been rigorously maintained, the information must be verified to exclude and anticipate problems. On-site surveys are necessary to verify the condition of the building, complete the building data, detect the possible presence of elements that could be problematic, or make first tests. The collaboration must also identify the missing information regarding the chosen methods that will have to be analyzed. Thanks to a first phase of understanding, a targeted analysis with more adapted techniques can be set up. This workflow will permit a first optimization of the time on site and the costs.

The different survey topics established on the first stage can be done through several methods involving different tools. For simple analysis such as visual checks, measurements, etc. low-

tech techniques can be used. They require little equipment but are limited by their performance and by the accessibility of the elements for the person in charge of the task. When using the collected information, they require a reprocessing step since they must be manually reintroduced in the working documents before being exploited.
To make surveys, the choice of methods depends on two parameters: the measurement and the acquisition of the data, therefore it is important to define the tools before choosing the right methods. [10]
High-tech methods bring more precision thanks to the use of technological tools. One of the best knowns is the 3D scan. It can measure at a distance thanks to laser sensors or images from cameras or drones. These measurements are then compiled with a computer tool to generate a point cloud where each point represents one of the measurements made. They can reach 50 to 100 million points and distinguish the elements of the building. This method allows a high level of accuracy and the survey of inaccessible elements such as roofs or entire facades.

Fig. 26: Point cloud of the Monmouth castle.

The acquisition is done automatically and can be integrated into BIM software. The current tools do not yet allow direct interpretation of the different elements and manual remodeling is necessary for the moment. [22] However, with high-tech methods the model is very fast to model and gains a great accuracy compared to low-tech methods. The 3D scan only measure the elements on the surface and does not identify the layers of materials. For a full understanding of a building there is no single solution; other sources of information are needed.

During a deconstruction, in addition to the surveys defined during the preliminary phase, some topics are mandatory and must be systematically controlled. It is the case of dangerous materials; it is imperative to verify that no material may contain asbestos, lead, coal tar, mercury, etc.; which are often present in the buildings. Those analysis are made by specialized companies that use specific tools. Asbestos, for example, is one of the most common components since it was widely used for its characteristics in paints and glues before being banned in 1990 in Switzerland for its danger to health. It is therefore very common to find it in buildings built before its ban. [33]

[33] "Amiante: du matériau miracle au déchet dangereux."

The presence of these hazardous compounds requires a specific sanitation that can generate important costs. During the rest of the deconstruction process greater vigilance is required. The materials in contact with them are also impacted, and their re-circulation may be compromised. These dangerous materials can be documented in the model (red color code for example) and thus give the good information of all the participants so that the model takes a great role of transmission of the data between users.

The different surveys can specify the data relative to the different materials and how they were implemented. The previously defined scenarios can be verified, and the choice of deconstruction methods validated with different actors. A good collaboration is important, it requires back and forth between the participants to refine the choices.

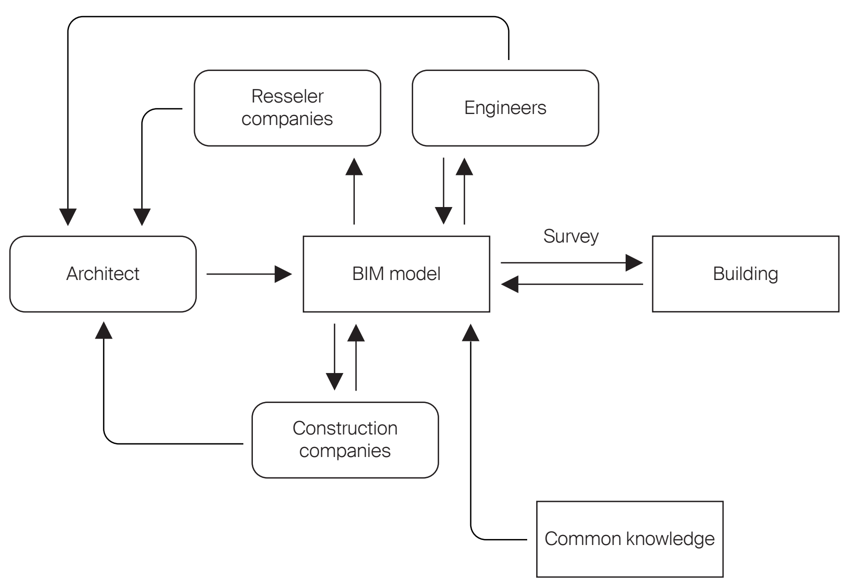


Fig. 27: Collaborative process needed for a systematic deconstruction

The new information must therefore be correctly integrated into the BIM model in order to be exploited in the scenarios and during data extraction. BIM tools allow the addition of new attributes to objects [1], which can be exported and stored in the IFC format. The use of BCF (commentary linked to the model) could also add

warnings or elements such as photos linked to specific areas of the building.

To choose the target materials, a hierarchy of the elements based on a comparison of their parameters could be added to the scenarios to refine the choices. To establish this ranking, the information related to the recoverability of the elements would be relevant: accessibility – reversibility – in connection with the state, etc.; they could be divided into two categories, according to eliminatory parameters and parameters that will lead to a rating.

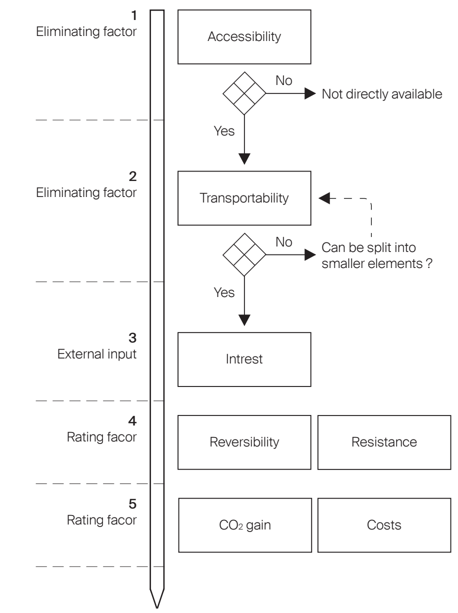


Fig. 28: Prioritization of the parameters to identify the materials to be targeted.

The precision of the objectives through documents and surveys is very important to choose the right methods to be implemented. They represent a major challenge for reuse with the lack of reversibility of the construction. Companies must develop new processes specific to each type of material and for each connection used.

For tiles, joints can be sawn to grant the separation of the tiles. For the deconstruction of concrete slabs, sawing methods allow the extraction of pieces that can then be reused as flooring for public spaces as it was the case for a building in the commune of Lancy in Geneva by *Belastock* in 2018. [8]

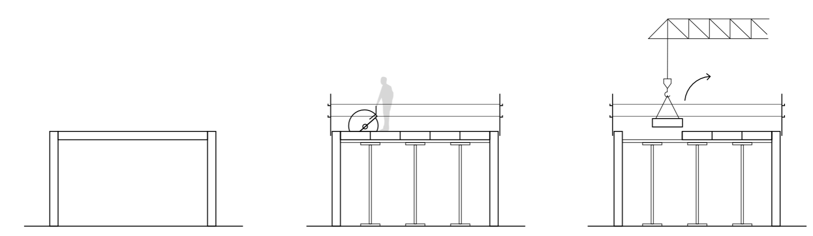


Fig. 29: Methods of deconstruction of a concrete slab by sawing, (building in Lancy GE by Belastock in 2018) .

These innovative and experimental processes are not widely used in the construction sector and suffer from a lack of visibility. During deconstruction, it is difficult to know the different methods allowing the dismantling of each type of material.

Reuse concerns the entire construction sector and requires a pooling of knowledge. Each trade and each actor have practices or experiences that he can contribute. The practice of reuse must be a "style of many hands." [9] As Barbara Buser from *Baubüro in situ* says, "we have to share our practices and strategies and our actions" [translated from French] [9] to give visibility and develop reuse. It is necessary to leave the current economic approach in which the companies remain owners of the methods they develop; on the contrary it is necessary to diffuse them to democratize them.

[9] C. Hegner van Rooden and I. Gutzwiller. 2019. "Tracés : Filière Réenploi."

In addition to visibility, reuse lacks value. As discussed earlier,

states play an important role. At the level of deconstruction, planners must show the CO_2 impact of the efforts they made. This can also represent a moral justification and empower the building owners. The data extraction that BIM processes allow is the perfect framework to establish a CO_2 balance of materials to be reused. If each material has information about the initial energy and CO_2 costs it is very easy to link the data with a quantitative to obtain a general balance from the IFC file.
The CO_2 balance could also be one of the final criteria for choosing one deconstruction path over another. Sawing one meter blocks instead of two meters blocks for example is already a big difference in energy consumption.

As well as CO_2, the financial aspect is important and remains one of the main issues of reuse. It evaluates and verifies the viability of the deconstruction. To facilitate the calculation of costs, classification systems of the elements can be integrated into the model and make it possible to distribute the various elements according to categories which will be allotted to the various categories of work. In Switzerland, a classification is proposed by the *SIA*: the ecccBat. [23] It has been elaborated for the construction of a project but this kind of classification could be established for the deconstruction and allow an easier costing.
The balance of costs for reuse of materials must consider several factors: the costs generated (preparatory work, labor which represents the major part, tools, and transport, etc.) as well as the gains made. The elements that will be reinjected into the construction have a value, currently difficult to establish, but with the development of the market it will be stabilize. In addition, it must be taken into consideration that the resold materials are no longer waste, and therefore a significant reduction in waste-related taxes can be made. [21] This is one of the factors that governments can use to support more systematic deconstruction.

[23] SIA. 2020. "ECCC-Bât SN 506 511 Code Des Coûts de Construction Par Éléments Bâtimen."

[21] N. Dantata, A. Touran, and J. Wang. 2004. "An Analysis of Cost and Duration for Deconstruction and Demolition of Residential Buildings in Massachusetts."

Reintegration of materials in a project

During a project, reintegrating reused materials remains a challenge. The resale market is still very little developed and the search for available elements requires a lot of effort. It is therefore important for the sector to evolve and for services to gain visibility, but to do so they need to have a sufficient stock of materials.
At the project level, great flexibility is required. The later changes are made, the greater the impact on coordination and costs will be. To promote the reintegration of reused materials, it should integrate them as early in the process as possible. The project must remain dynamic. The use of a digital model permits this dynamism by facilitating the collaboration and the update of the documents; the modifications do not require too much work.
With BIM tools like Revit, elements are grouped by type and each

repetition is called an occurrence. Changing the characteristics of the type automatically changes all occurrences. Let's take the example of doors, if an available stock is identified, simply changing the type with the element's characteristics will change all targeted objects in the project. Afterwards, a clash detection is used to verify that the new materials do not conflict with other parts of the project. BIM methods help reducing the number of errors.

To gain in precision and have a more efficient integration of reused materials the elements should not be modeled in the project by the architect. It would generate too much risk of error during their retranslation. They could be directly imported via a pre-existing BIM file.
This is already done for some suppliers of materials and equipment in the construction sector who make available BIM files that have an advanced modeling and integrate all the necessary data including assembly guides, technical data, etc.
Once again, there is the question of the format of these files. IFC would be the most relevant but does not allow a fluid and fully exploitable integration in the various modeling software. They must be of the native format of the software to be completely modifiable and fully integrated with other elements. The BIM formats currently provided in databases are available in several formats for the main software: Archicad, Revit, Sketchup.

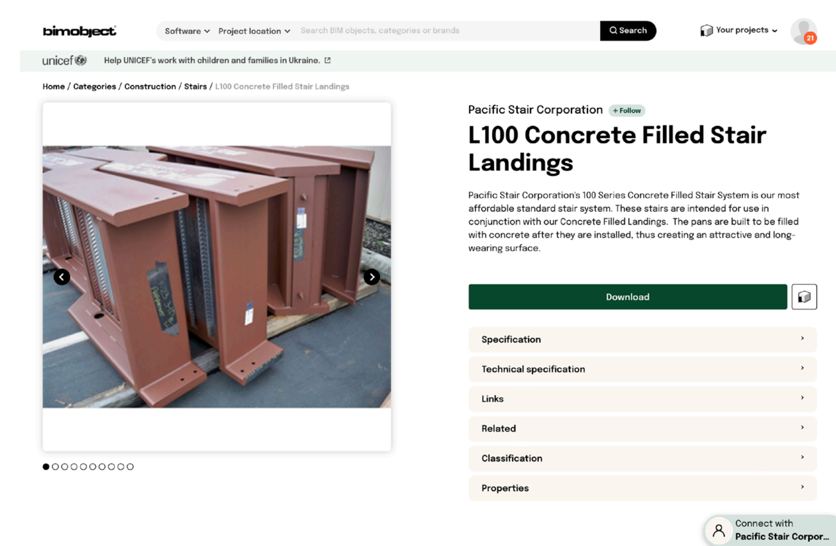


Fig. 30: Material database of a staircase from Pacificstairs available on Bimobject.

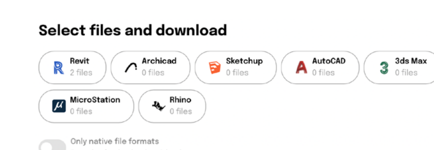


Fig. 31: Type of file available for the elements on BIMObject.

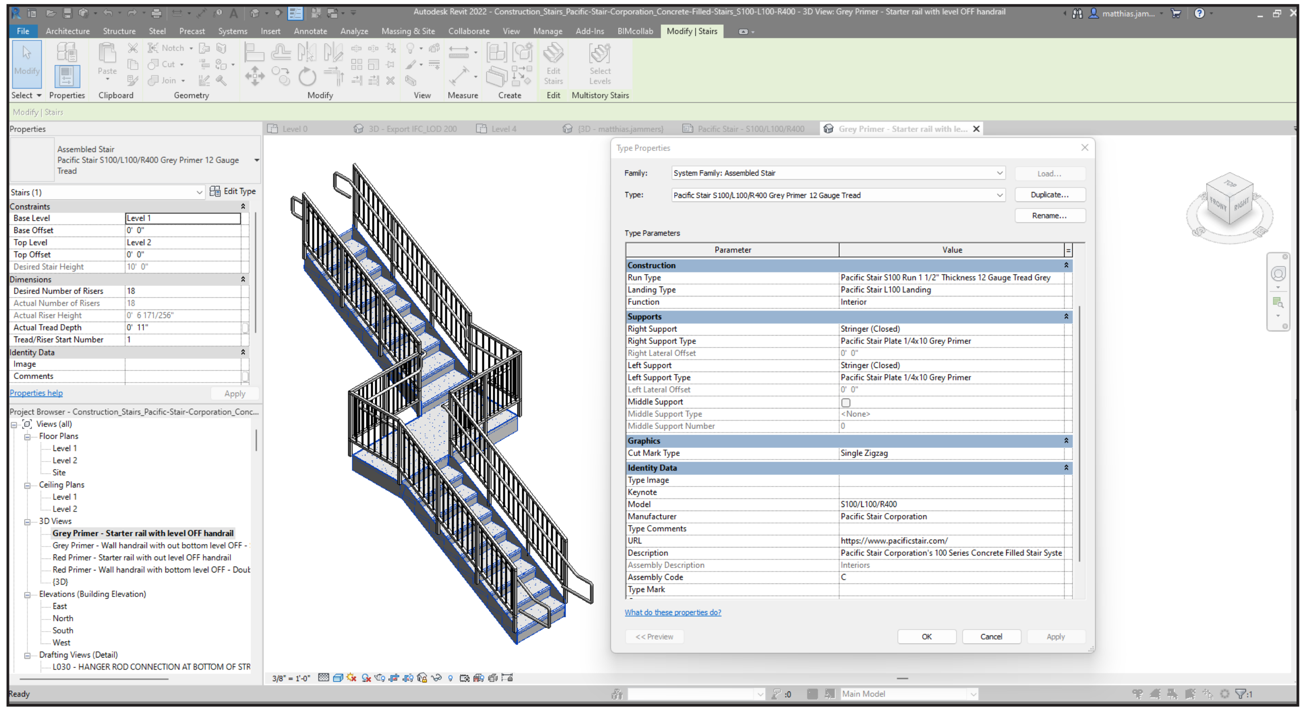


Fig. 32: Opening the BIM file of the Pacificstaris staircase, on Revit.

Re-used materials are mostly not in standard anymore and need a lot of information about their properties to be correctly integrated. We talk about "materials passport" [8], when a document centralize the information about an element; it allows the exchange of the data. The addition of a BIM aspect would give it even more strength and facilitate its use.
The architect will be the person who will use the material files in a project. It must therefore be interesting that the profession creating the file during the deconstruction is the same as the reintegration one to understand the needs to be integrated. They need to be identified when creating the file to make it as relevant and useful as possible.
In an ideal case, the data that will be used for deconstruction and reintegration should already be implemented in the initial construction. At this stage, the architect is also the best suited to anticipate and ensure the transfer of the material data its passage to new use cycles.

Discussions

Plug-in

BIM is a work process around a mode for which tools are used. These tools can evolve very quickly and do not offer all the uses that one could wish, they have limits. That is why various extensions, called plug-ins, are frequently developed to bring new functionality in line with needs. They can be developed directly by the software companies or by independent companies or individuals.
This flexibility of use makes the field of possibilities very large and shows the strong potential of BIM for the multiple uses and needs of construction: management, cost, planning, modeling, simulation, algorithmic design [7].

Deployement of BIM

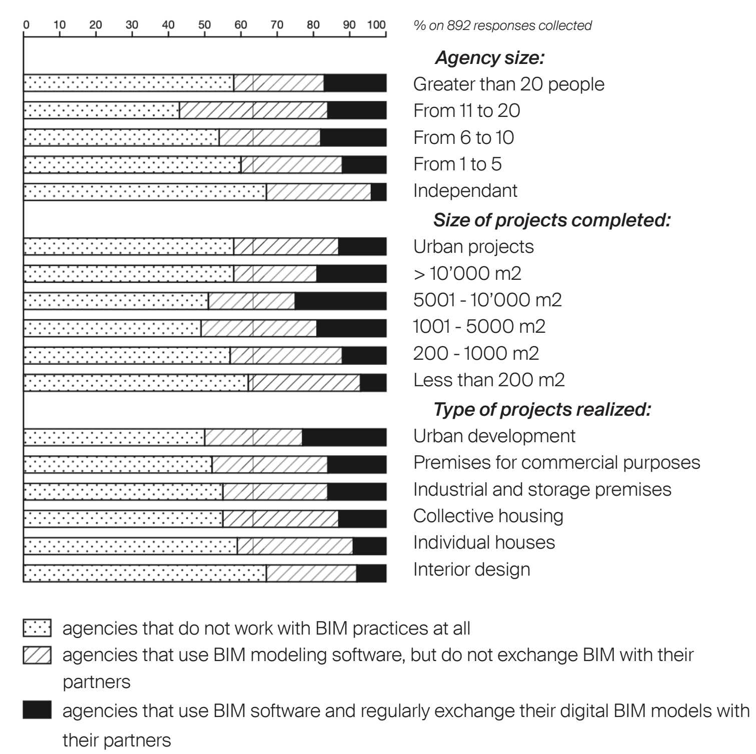


Fig. 33: Profile of French architectural offices working in BIM.

In the professional environment of the construction industry BIM deployment is still a major challenge. As the study by Hochscheid and Halin in 2020 [22] illustrates, a vast majority of architectural firms do not use BIM tools, and for those using it, many are doing it in a collaborative process. Less than 20% of firms (of any size) are truly exploiting the potential of BIM. This difficulty in transition can be partly explained by a distrust of architects who see BIM as a limit to creativity as Tuba Kocaturk and Arto Kiviniemi state in *An Innovative Approach to Technology Mediated Architectural Design Education (2012)* [25]:

[25] T. Kocaturk and A. Kiviniemi. 2013. "Challenges of Integrating BIM in Architectural Education."

> *"By entering into an unchartered (BIM) territory architect can become a mere player, one of "the others", instead of "the creator, the innovator"."*

The potential of BIM for architects is not understood. The interest is often seen as limited to large projects [26], when it can be used at any scale, even in a competition stage.

[26] T. Puolitaival and P. Forsythe. 2016. "Practical Challenges of BIM Education."

This lack of understanding also explains the lack of knowledge about BIM tools. Being based on new technologies, BIM needs to be introduced to the workflow of an office at some point. This implies changing work habits, adapting and learning, thing that many offices are not ready to do. The lack of knowledge is also seen in BIM-oriented projects, where firms respond even if they do not have all the capabilities. This leads to many complications and can put the office in trouble. [31] There are weaknesses in learning BIM and a big gap between the expectations of the industry and the level of young graduates coming out of school. Agencies are using more and more BIM software and require knowledge in this field; they expect new generations of architects to bring new knowledge.

[31] O. Fleith. 2022. Utilisation du BIM dans un cadre professionnel.

At the university level, BIM is only very slightly integrated into programs that are already very dense and difficult to adapt. The teaching staff, as in the professional field, does not have the knowledge nor interest for BIM. [18] [26] Its integration in the programs is therefore not promoted. The EPFL case is a good example. Currently, only one laboratory gives courses related to computer tools and with one course of introduction to BIM and a teaching unit for master students and only a brief introduction in bachelor. Although the teaching is still very limited on the subject, this laboratory will soon close, which strongly risks compromising this teaching for architecture at EPFL. The students begin to realize the importance of these classes and are mobilize for their maintenance. [17] The difficulty of teaching lies in the easy of finding teachers as well as availability of basic resources which need to be close enough to real cases in the industry.

[18] K. Dithebe. 2022. "Building Information Modelling Pedagogy: A Step in the Right Direction for the Construction Industry."

By learning about BIM from the beginning of their studies, students are able to grasp the BIM processes and understand them to exploit them and make them fit their needs.

> *"Wang and Leite (2014) highlighted the importance of teaching BIM as a process improvement methodology rather than a technology." (Taija Puolitaival and Perry Forsythe, p. 4) [26]*

The transition from drafting to CAD was made with software

but did not change the working methods. In contrast, BIM is a methodology in its own which requires more than just an understanding of a software.

The university environment has the strength of grouping different sections and offers the possibility of developing multidisciplinary teaching which could highlight the importance of collaboration. Thus, an understanding of the needs and expectations of the various trades could be integrated, in particularly in terms of information and BIM practice.

Outside of the university setting, apprenticeships are just as difficult. The training offers are very limited and expensive. They are not all at the level of expectations that BIM requires. A form of abuse and disillusionment is forming around this sector, especially in Switzerland. [30] However, there are an increase of projects that make learning BIM more accessible like the training platform currently developed by Élise Hautecoeur, lecturer at EPFL, called *OpenschoolBIM* which is about various concepts and tools of BIM

Ownership of the data

The documentation developed for a building is part of the deliverables of the service of an architect. These documents belong to the owner and will be useful during the exploitation of his work.

At the level of reuse, the creation of a passport of materials with BIM models requires time and is specific to each element. They aim to give visibility to materials and make them easier to reuse. Therefore, they bring advantages.

How should the extra work be considered and compensated? The materials are already struggling to compete, can the modeling costs be integrated in addition?

Once the materials have been disassembled, the person in charge of the deconstruction has completed his role. Who owns the rights of this data? Should it be completely free and accessible to everyone? The notion of ownership of the data is an issue that could influence the willingness of stakeholders to provide this work or not.

When a general contractor manages the deconstruction and then reuse the materials in several of their projects the benefit goes directly to them. If the two steps are completely independent, it is difficult to require additional work without direct return to implement it.

The benefits and requirements brought by governments would directly influence the answer to this question.

Leasing

So far, we have approached the issues of reuse in a binary way with the objective of addressing the life cycle issues of materials. It might also be interesting to question the current dynamics of new materials.
They are of lower quality and once the guarantees are over, the suppliers have no more responsibility towards them. The objective is no longer to sell the most qualitative products, but sell it as cheap as possible. This is what makes today's materials and buildings quickly obsolete.
A new practice is starting to emerge: Leasing. It is already developed for vehicles, and more and more for electronic products. Companies no longer sell the products, they sell a service: they rent a product for a period, then recover it, and rent it again. With this dynamic, they are responsible for the product and have a vested interest in making it last as long as possible. They also become responsible of what happens at the end of the product's life and the way the materials are being cleared. [8] With this practice, we could tend towards an economy of responsibility. [19] If it was applied to construction elements, it would result in buildings being better constructed and more evolutive in time according to needs. Philips lighting company is an example. They begin to lease their installations.
In a case like of leasing, the use of BIM model would be very useful to follow-up and for the maintenance of materials. The data could track the material in the different cycles and facilitate the different assembly and disassembly with the maintenance of records. These documents would remain property of the company and would be directly useful.

Opening on the master project

With the development of digital tools and their democratization in construction, it is important as an architect to be interested in it and not to be overtaken by the practices of the sector. BIM tools should be exploited to make construction methods evolve towards more environmental concerns.

In connection with the various issues of reuse, we have highlighted the potential of BIM to make deconstruction more efficient: exploitation of information, upstream planning, collaboration and mutualization of knowledge and data extraction.
In these processes, the BIM model is central and is based on the available elements. The existing documentation follows a building throughout its operation and must be as complete as possible. The needs must be identified as soon as possible, and it is even better if it is from its creation.

Following this Enoncé théorique, the work could focus on understanding the needs and their integration into a deconstruction process.
Based on a sample building, we could start with the assumption that an IFC model is available and then develop a plan leading to a methodical deconstruction.
The IFC format must be privileged to perpetuate the data since it is the standard. It seems relevant to deploy two different workflows, one based on the most common tools (Revit, etc.) and using native formats requiring the re-translation of part of the IFC data; and the second one setting up tools working directly with the IFC format. This comparison would put forward the use of documentation and the needs that are linked to it.
In connection with planning, collaboration must be put back at the center of the process. A reflection must be developed on data transmission practices between the stakeholders. New types of documents or representation methods could be explored to guarantee a good understanding from the planner to the worker on site during the demolition: partial or filtered identification plan according to the recoverable or not of materials.

Conclusion about BIM process integration

Reuse is a direct response to the high obsolescence of buildings and materials. It allows the construction sector to open up to more responsible practices and respond to current environmental issues which has great environmental responsibility.
Many actors are starting to develop methods, but are still not widely available and subject to many contraints: technical, economic, methodological and cultural.

Reuse is a topic and a challenge common to all construction professions and requires the mutualization of their knowledge and practices. They all have an influence on the issues and cannot solve them all individually.
The architects are ones of the central stakeholder in a project. They are greatly involved in the planning and collaboration and have an important part of responsibility regarding the construction practices currently implemented. Their skills and sensibility should facilitate the reintegration of materials in new projects and could give them a new role as planner during the deconstruction of a building.
Currently pushed by economic factors and time limits, buildings are mostly demolished. A planning and collaboration between the professions would allow a reconsideration of the materials and to take the reuse out of its actual scale to turn it towards the whole systems of a building.
The evolution of demolition towards a more systematic deconstruction led us to determine the potential that BIM could bring to the new processes. Collaborative work around a digital model offers the possibility to understand the building as a whole and to identify its different components.

The work between the different actors must be based on the existing documentation to be as relevant as possible, the data must have been developed by taking into consideration these future uses. The architect should be responsible for providing the necessary elements for maintenance and to allow the re- circulation of materials in the future from the end of the construction of a project.
The BIM model is an element that permits the centralization of all information in a document. The standard IFC format used for the deliverables allows a good exploitation and an interoperability with the various tools of the collaborators, and ensures a sustainability. The model is the basis to define the objectives and identify the methods to be implemented. This planification passes by scenarios based on the materials, their connections, and their interactions within the building.
The implementation of BIM at the deconstruction scale offers many tools to plan and value material saving actions. However, integrating BIM processes in a systematic way can be a challenge as some of the main tools have gaps in using the IFC standard. Practices need to become fully open to foster interoperability like OPEN BIM does and users must get out of the grid that software companies have.
It is therefore important to define efficient practices and processes relevant to all tools. Actors need to be guided and examples need to be made to confirm the feasibility of the approach, as Baubüro is doing with their pilot project.

Finally, it is true that BIM tools offer great opportunities based on very powerful technologies but we must not forget the human aspect which remains very important in their use. Learning and sharing knowledge are vital to allow a good transition to BIM practices.

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Table of illustrations

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