Building Façade System for Deconstruction

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Because of obsolescence and deterioration of Building Façade System (BFS), existing façade systems are increasingly being restructured or demolished. Such constructional interventions cause excessively resource consumption and waste generation, which have several environmental and ecological problems. These problems are required performing the sustainable environmental solutions. BFS for Deconstruction may give guarantees for careful dismantling of a BFS so as makes possible the recovery of BFS parts promoting reuse and recycling. In that respect, BFS for Deconstruction is an alternative to façade demolition in consequence of increasing environmental concerns and can be seen as a key for sustainable construction. The basis of this paper is to discuss the BFS for Deconstruction concept which deals with BFS that can be deconstructed and dismantled so as to recover as many parts as possible without leaving any debris on site. The paper is determined the reasons of restructuring and demolition of BFS. The design considerations of the BFS for Deconstruction are explained, and the best BFS organizations for deconstruction and the main recovery potentials of BFS parts are researched in this paper. Consequently, principle information for architects to understand and use BFS designing for Deconstruction is presented.

KEYWORDS: Building Façade System, Deconstruction, Disassembly, Designing for Deconstruction, Recovery Potential, Sustainability

Introduction

In the construction, maintenance, restructuring and demolition phases of buildings, enormous amounts of materials are produced that they result in significant waste streams and excessively resource consumption in most countries. Due to the increasing problem of the waste, which has several negative environmental, economic and social impacts, architects are façed with the pressure in building designs to meet criteria of sustainability, e.g. limiting the discharge of pollutants into the environment. According to “Regulation (EU) No 305/2011”, the construction products and works must be designed, built and demolished in such a way that the use of natural resources is sustainable. Sustainability is necessitated that construction works, their materials and parts must be reused or recycled after demolition (EU 2011).

“Building Deconstruction” is a demolition approach where a system is carefully and methodically disassembled and decomposed, so as to recover (reuse or recycle) as many system parts as possible. Deconstruction process comprises of taking a building system apart into its parts in such a way that they can be more readily reused or recycled (Guy and Shell 2002).

The building system can be divided into the independent subsystems and parts to facilitate deconstruction of the building system. Stewart Brand categorizes the subsystems of a building system into, structure, skin, services, space plan and stuff as sharing layers of building change, and every each has different rates of change (Brand 1994). The structure subsystem is not much subject of restructuring and demolition during the whole building life cycle because it is the base part of the building system, and has the longest lifespan. The skin, also known as the BFS, can

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be seen as one of the most critical restructured and demolished subsystem in building system. Therefore, when looking at the whole lifespan of a building system, we can see that the BFS has a weak link to the building system and must be considered the one of the main resources in waste generation.

Generally problem is that the BFS and its parts are not designed for sustainability. There is the potential for sustainability of BFS and its parts in the lifetime when applying the BFS for Deconstruction approach. The primary goal of the BFS for Deconstruction approach is to use BFS and its parts sustainable, to reduce the impacts of pollution, to reduce resource use, and to increase economic efficiency in the removal of BFS, as well as recovery of system parts for reuse and recycling.

Designing for Deconstruction

DECONSTRUCTION is the systematically dismantling and recovery of the building parts from a building system at the end of the building's life, without damaging, and to preserve them in the resource stream for their future reuse and recycle. Deconstruction technique is in contrast to DEMOLITION, and it is an alternative to traditional demolition where virtually all parts end up in a landfill (Storey et al. 2003). Deconstruction is related to the ability of building parts and systems to be easily replaced, displaced, reconfigured, reused, and recycled. DISASSEMBLY is similar to deconstruction, but not necessarily to reuse or recycle building parts (Hobbs and Hurley 2001). In order to achieve deconstruction, building should be designed for disassembly. In that respect deconstruction with associated disassembly properties can be seen as a key for sustainable construction.

DESIGNING FOR DECONSTRUCTION (DFD) can be described as the need to design building system and its parts to be easily disassembled therefore allowing them to be recovered in the total life cycle. DfD concept in architecture is borrowed from the fields of disassembly, reuse and recycling in the consumer products industries. The basic goal of DfD is to increase resource and economic efficiency and reduce pollution impacts in the adaptation and eventual removal of buildings, and to recover building parts for reuse and recycling. The practice of DfD will allow existing and new building stock to one day serve as the primary source of materials for replacement construction, in effect mining and harvesting existing building stock rather than the natural environment. This resource flow will be encouraged by aging and obsolescent buildings and dwindling natural resources (Guy and Shell 2002).

DfD has gained popularity over the last few years in theory, but few projects exist where the concept has been put into practice. There are a number of barriers to materialize of DfD as follow (Tingley 2012):

- Perceived risk in specifying reused building parts
- Negative perception of second hand building parts
- Financial and time constraints of DfD
- Designing with inseparable composite parts
- Performance risk in reused building parts
- Designing for robustness
- Lack of market for reused building parts
- Unable to guarantee that building parts are salvaged in a safe manner
- Unsuitable and inaccessible joints used
- Lack of information about parts and technique used
- Reinforcement corrosion in concrete is not to be visible
- Coatings on steel parts could contain banned chemicals

- Visible degradation and contamination of reused parts
- Loss of craft skill to create exposed connections
- Site or storage requirements for recovered building parts

DfD barriers are not insurmountable. In order to overcome the barriers, following DfD principles/ strategies must be considered (Crowther 2000, Crowther 2002):

- Use recycled materials
- Avoid toxic and hazardous materials
- Minimize the number of different types of material
- Make inseparable subassemblies from the same material
- Avoid secondary finishes to materials
- Provide standard identification of material types
- Minimize the number of different types of building parts
- Use a minimum number of covering building parts
- Use mechanical connections rather than chemical ones
- Make chemical bonds weaker than the building parts
- Use open building system, where parts are changeable
- Use modular design systems
- Use assembly technologies that are compatible with standard building practice
- Separate the carrier parts of the building from the others
- Provide access to all parts and connections of the building
- Use parts that are sized to suit the intended means of handling
- Provide a means of handling parts during disassembly
- Provide realistic tolerances to allow for movement during disassembly
- Use a minimum number of different types of connectors
- Design joints and connectors to withstand repeated use
- Use a hierarchy of disassembly related to expected life span of the parts
- Make the most reusable parts most accessible
- Standardize the parts while allowing for an infinite variety of the building as a whole
- Use a standard structural grid
- Use lightweight parts
- Provide spare parts and on site storage for them
- Sustain all information on the building manufacture and assembly process.

Obsolescence and Deterioration of BFS

The service of a BFS is what provides the values for the owners, users and public. When the service values of a BFS or its parts decrease over time, their service life ends, and they become waste disposal. Service lifetime of a BFS is the time that the BFS and its parts can be expected to be serviceable for required and intended performances and features. Because of two distinctive processes: ***Deterioration*** and ***Obsolescence***, the service value of a BFS is reduced after the construction and in the use. Deterioration is caused by the decreasing physical performance of the BFS and its parts, while obsolescence is due to changes in technology and aesthetic conditions (Marteinsson 2005).

When the capacity of a BFS or one of its parts to perform the function for which it was intended declines, it becomes physically deteriorate. Physical deterioration of BFS over time is inevitable and it brings degradation and performable inadequacy. Specific interventions (maintenance, refurbishment, retrofit, etc.) are necessary to overcome the physical deterioration of BFS in order to keep them having expected performance properties. For example, repairing or replacing a wall flashing and the seals in a window (Fig. 1). The physical sustainability of façade systems requires durable parts resist all physical factors in the external and internal environment over the lifecycle.

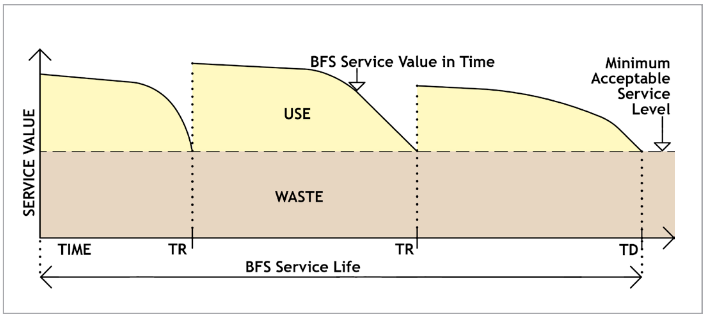

Fig. 1
Service life time of BFS

It is a common design attitude characterizing the BFS by fashion, vogue, personal taste, aesthetic culture, etc. The fashion in architectural style may change or the BFS may look old and fail to satisfy an inspiration to be associated with up to date parts. BFS may deem unacceptable by owners or users if the appearance is outdated and incompatible with their aesthetic taste. People's aesthetic tastes change as an expression of themselves, and fashion changes with respect to day. A future architectural style cannot be predicted precisely. Generally the changes in fashion will provide an adverse reaction against styles, which characterized the immediately proceeding era. The effect of aesthetic obsolescence of the BFS is greater in commercial buildings because this kind of buildings with new architectural styles can fetch higher rental values (Baum A. 1991). The decline in the aesthetic service value requires the BFS to be reconfigured to make it attractive and competitive again (Fig. 1). Design the appearance of the BFS so that it does not quickly become uninteresting or unfashionable, thus ensuring that the aesthetic lifetime of the BFS is not shorter than its physical lifetime.

Rapid technological changes have caused many industrial and commercial properties to experience technical obsolescence. New BFS technologies are being developed at an increasing rate. Because of technologies continue to evolve, existing BFS becomes technically obsolete. Parts of BFS could be designed for technical upgrade, so that when old part technologies become obsolete, the parts can be upgraded to incorporate the new technology. For example, fitting new technology glass units into an existing curtain wall. In the technical obsolescence time, the BFS must be upgraded for being competitive and attractive regarding the progressive technological and production advantages. The aesthetic and technical sustainability of BFS requires that it should be designed to facilitate reconfiguration and restructure for changing demands over the lifecycle.

We couldn't stop factors as physical, aesthetic and technological which cause deterioration and obsolescence of BFS, but we could be accommodated them by ***BFS for Deconstruction***. When the accommodation can't come true and the actual service value of the BFS comes down, it and its parts may constantly be waste disposal.

BFS Design Considerations for Deconstruction

We can describe BFS as a physical whole that is obtained by bringing together the certain physical parts according to their functions. According to their primary functions in the BFS, physical parts of BFS may be organized in three main groups as: *Façade Elements, Façade Components and Façade Materials.*

BFS is composed of three main façade elements, such as, ***external wall, window*** and *external door* (Fig. 2). A façade element is a major façade part that is obtained by configuring of the various façade components by various techniques and methods. An external wall element in a BFS may be configured using the following façade components: *Carrier, Finish, Insulator and Supple-*

mentary (Fig. 3). Window and external door elements in a BFS are generally an assemblage of following components: I*mmovable Frame, Movable Frame, Infill Unit, Sill, Weatherproofer and Supplementary* (Fig. 4). A façade component is obtained by combining of the treated façade materials. Façade materials are the constituent parts from which all other parts of BFS are made, such as concrete, clay, glass, steel, aluminum, timber, plastics, natural stone, gypsum, bitumen, etc.

Some functions of BFS may not be needed in some element types. Therefore, façade elements do not have to include all the components mentioned above. In monolithic walls, such as load bearing masonry, a single component may act as the carrier and the finish. Composite walls generally assign critical control functions such as the control of heat transfer or air leakage, to separate components, or combinations of components.

Deconstruction of the BFS is related to the ability of the façade parts to be easily disassembled, replaced, reconfigured, and reused. In order to accomplish BFS for Deconstruction, BFS design is primarily needed focusing on the number of design considerations such as: *Functional Decomposition of BFS, Systematization of BFS Parts, Assembly and Disassembly Sequences, Connections of BFS Parts, Recovery Potentials of BFS Parts.*

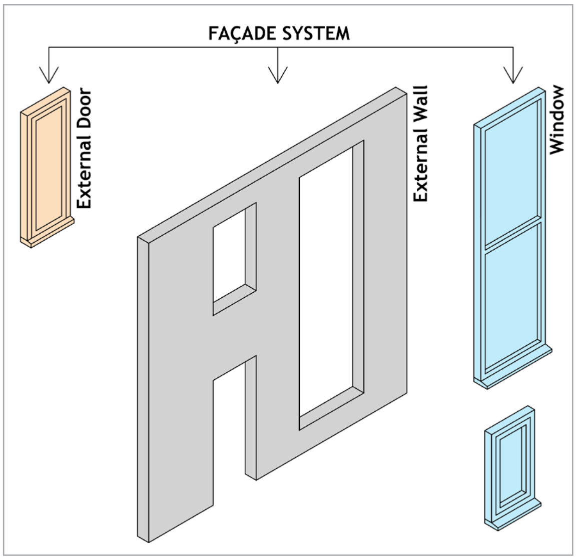

Fig. 2

Elements of BFS

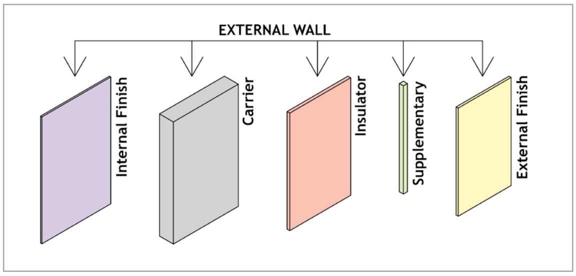

Fig. 3

Components of External Wall Element

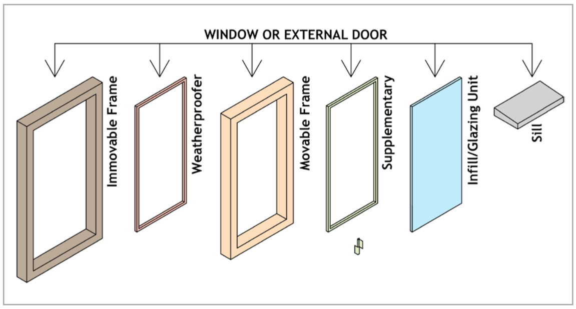

Fig. 4

Components of Window/ External Door Element

In BFS design for deconstruction, the physical organization of the BFS may be formed according to the functions satisfied by the façade parts. A façade part can be disconnected from the BFS, if it is defined as a functionally independent part of the BFS. Functional independence of BFS parts can be achieved by separation of the functions and allocation them into separate parts, in other words by functional decomposition (Durmisevic 2006).

The BFS has to serve a number of functions in the building system, and generally assign these functions to the separate parts of the BFS. Thus each physical part serves for specific functions of the BFS. Functions that are performed by a BFS and its parts can be hierarchically decomposed into three main levels (groups) in order to identify functions with their different overarching effects in the BFS (Fig. 5). Functions that have much more overarching effects in BFS should be higher levels of the hierarchy. Hierarchically decomposition of the functions into different levels according to main overarching effects is to reduce interrelated connections between façade parts that meet the functions.

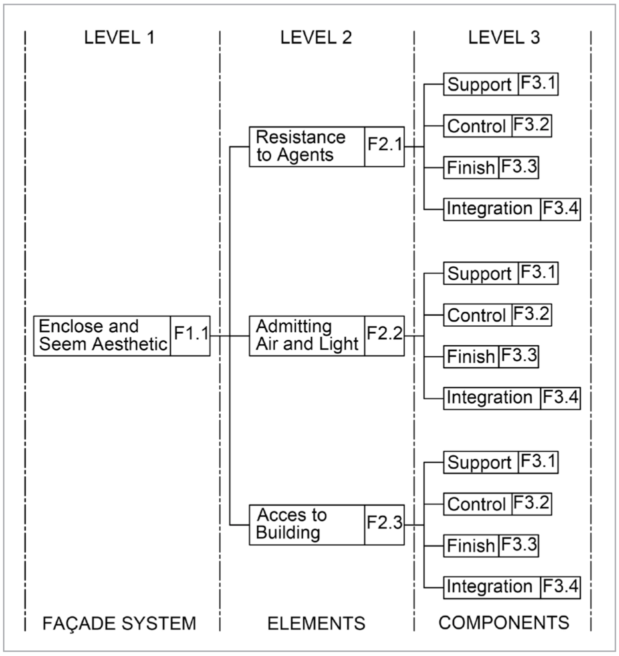

Fig. 5
Functional decomposition pattern of BFS

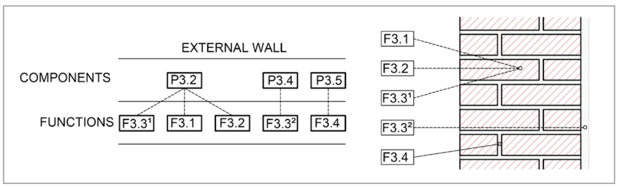

Fig. 6
Closed system external wall element without functional decomposition

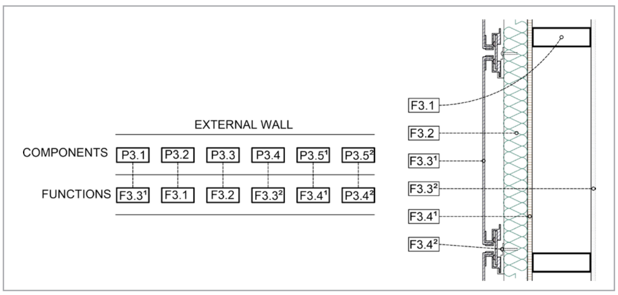

Fig. 7
Open system external wall element with functional decomposition

The primary function of a BFS is to enclose an environment and separate the internal and external environments. BFS has to provide not just separation but also the visible skin to the building. Thus, the BFS is seen the critical important to owners, the architect and the public. BFS mostly is designed according to the fashion and the aesthetic style of the time it is built. BFS, well known as a basic aesthetic element for buildings, need to be able to change satisfying aesthetic and fashion preferences.

There are three main functions met by façade elements on the level 2: to resistance to the loads and to the flow of mass and energy; to admit light and fresh air; to provide easy access to the building. On the level 3, there are more specific functions met by façade components: support, control, finish and integration. Support function is to load, resist and transfer all the structural forms of loading impose by the internal and external environments, by the BFS, and by the building system. Control function is to manage, regulate and/or moderate all the factors (the flow of air, moisture, heat, sound, etc.) due to the separation of the internal and external environments. Finish function is to finish the façade surface and to meet relevant visual, aesthetic, wear and tear, etc. performance requirements (Straube and Burnett 2005). Integration function includes space adjusting, fastening, locking, etc. supplementary performances. Each function must satisfy by the relevant façade part.

A façade part may be attached to a part of the same façade assembly, to a part of the adjacent façade assembly, or to a part of adjacent other building subsystem (roof, floor, structure, etc.). All these interactions create dependencies. Strong dependency and fixed joints between parts in a façade system are boundary condition for BFS design for deconstruction. BFS, whose parts have multiple functions, and are not systemized into functionally independent assemblies, represents a closed/static system. Closed BFS is designed without functional decomposition (two or more functions are integrated into one façade part). For example, mass and thickness a carrier core component in a traditional masonry external wall accommodates the mixture of three functions, support, control and finish. Such components are static and fixed parts in a BFS (Fig. 6).

A BFS composed from independent parts is an open system that has a capability of major reconfiguration. The parts of an open BFS can be changed easily, and then is considered changeable and demountable parts offer an opportunity for BFS design for deconstruction. One of the design characteristics of an open system is total separation between different functions on all levels of system integration. By decomposition of BFS functions into number of independent parts the BFS becomes more deconstructable, because it can easily be disassembled, replaced and reconfigured according to the new requirements regarding to physical deterioration, aesthetic and technologic obsolescence of BFS. At the same time, the reuse potential of BFS is increased (Durmisevic 2006) (Fig 7).

Systematization of BFS Parts

Systematization is based on specifying parts and groups of parts in a system. The focus in BFS design for deconstruction should be on systematization of BFS into independent parts assembled in a hierarchical organization suitable for accessing and disassembling. The term the hierarchical organization of BFS parts explains a BFS order in which BFS parts are interactive subsystems within the framework of the hierarchical order. To obtain BFS design for deconstruction, two types of relations in the hierarchical organization of BFS, have to be considered: between groups of parts and within groups of parts. In BFS design for deconstruction works, the BFS may be formed of four hierarchical levels which consist of a number of parts and groups of parts. Each of these levels has different intended service life time within the framework of the hierarchical order. If the systematization of BFS parts is based on hierarchical organization, the long lasting BFS parts (have longer service life time) are placed on higher level of the hierarchy and the fast changing parts (have shorter service life time) belong to lower level for disassembly. For example, because they have shorter service life time, components in a BFS are on lower level than elements in the hierarchy (Fig. 8).

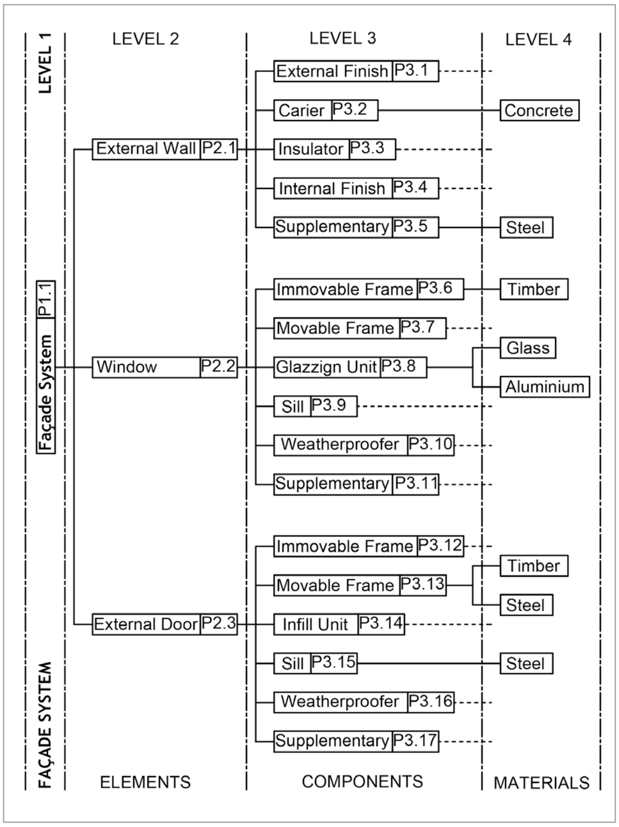

Fig. 8

Hierarchical organization pattern of BFS parts

To provide independence of a group of parts on one level from the other groups of parts, each group of parts should have its base part which integrates all surrounding parts of that group. The base part is an intermediary of the relations between different functions and surrounding parts. According to this, BFS could be defined through relations between the base and other parts that are placed on different levels of the hierarchical organization. The base part is a connector of all independent parts in a group of parts, and also makes the connection with other groups of parts.

On the façade system level, an element, such as external wall can be the base element for others, such as windows and external doors. On the external wall element level the load bearing components (such as a carrier) can be the base component for all other components of the element (such as external and internal finishes, insulator, supplementary, etc.). On the window/external door element level frame components would have the base components which bear all other parts of the window/external door. Such systematization of façade parts through base parts and their connecting parts stands for the better control of the BFS, the use of exchangeable parts,

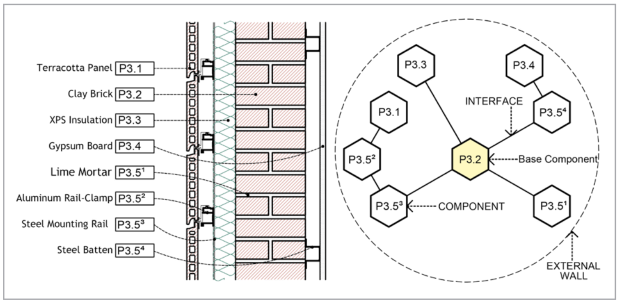

Fig. 9
Systematization of an external wall element

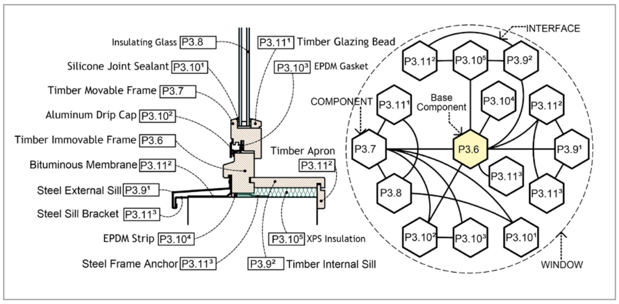

Fig. 10
Systematization of a window element

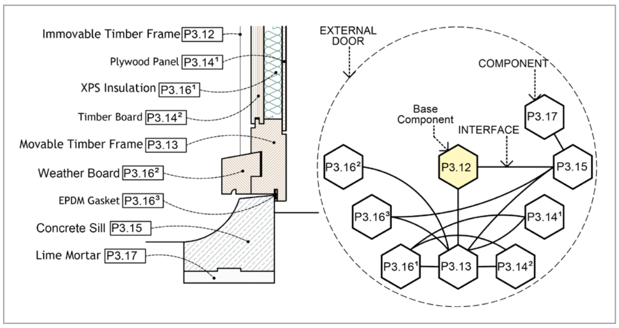

Fig. 11
Systematization of an external door element

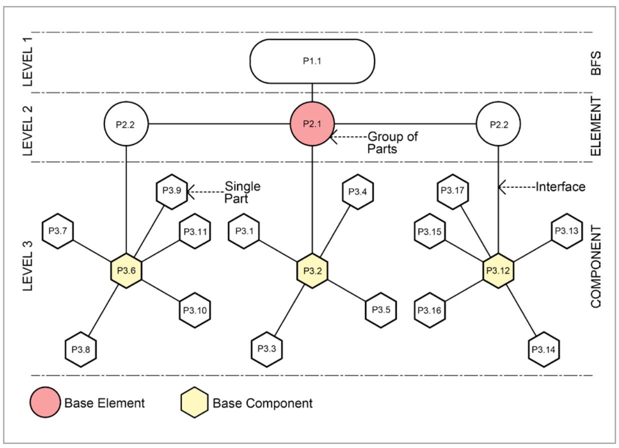

Fig. 12
Open BFS systematization

and total disassembly at the end of life cycle if the physical organization of parts is suitable for disassembly (Fig. 9, 10, 11).

In order to achieve an increase the disassembly potential of a BFS, it should be systematized as an open system. The first step toward open system is to minimize the number of interfaces between subsystems within the system. For a hierarchical system to be an open system, its subsystems (parts and groups of parts) must be independent from others in terms of the physical and the functional concerns. In open BFS, parts are kept independent from each other by creating dependent relation only to the base part. Therefore, open BFS allow easy access and disassemble for rapidly changing physical parts, and extend the total lifetime of BFS without demolition waste in the cases of all obsolescence and deterioration (Fig 12).

Assembly and Disassembly Sequences

Design for disassembly is developed from design for assembly. The goal for design for disassembly is to find the correct borders between useful subassemblies (Luthrop 1997). Most buildings are designed to be mountable, but not demountable. For this reason assembly of buildings can be seen as a complex sequence of connecting and a process that may involve a number of specialist and special machines. The disassembly of a building may sound like the opposite of its assembly, but in practice it seldom occurs this way. The reversal of the assembly sequence is usually practiced as demolition (Crowther, P. 2002).

One of the main design considerations for disassembly of BFS is to expedite the understanding and viability of a disassembly sequence for either parts or the groups of parts. Sequences of assembly create dependencies between BFS parts. An assembly hierarchy shows the BFS breakdown from assembly point of view. There are two main types of assembly, parallel assembly and sequential assembly (Fig 13). A parallel assembly sequence can make a BFS assembly process faster, and a sequential sequence creates dependence among parts and makes substitution and replacement more difficult. Parallel assembly depends on the type of connections between BFS parts. Each part in a sequential assembly is fixed by a newly assembled part; therefore a linear dependency is established (Durmisevic, 2006).

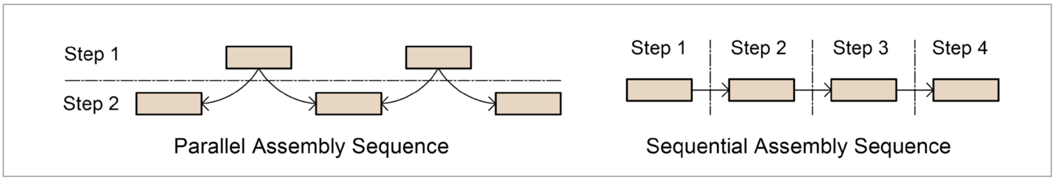

Fig. 13

Assembly sequences (Arrows represent assembly direction) (Adapted from Durmisevic 2006)

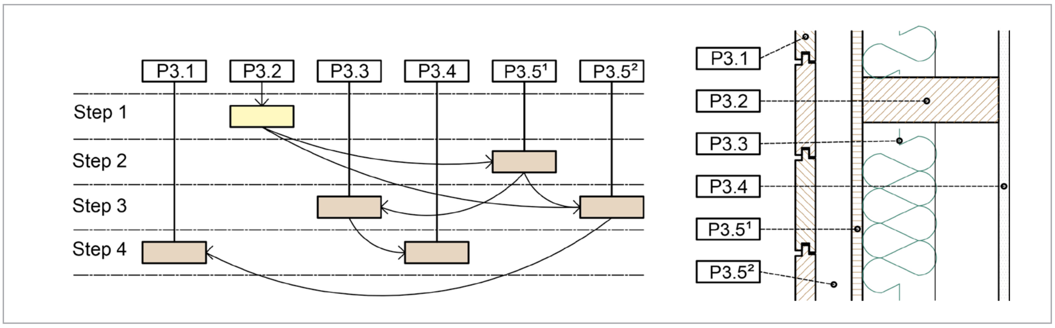

Fig. 14

Assembly sequence diagram of external wall components

The systematization framework of BFS parts may be explained by the assembly sequences of BFS parts. The **Fig. 14** presents the assembly diagram of the external wall components into a BFS. The base part P3.2 is assembled first. Before assembling the other components, P3.5^{1} is connected to the base part. In Step1 and step 2 a sequential assembly sequence is followed. Then P3.3 and P3.5^{2}, and finally P3.1 and P3.4 are assembled following a sequential assembly sequence.

Assembly sequences can be affected the connection types and the edge geometry of the BFS parts. Interpenetrating geometry is less suitable for disassembly, since parts can be disassembled in only one direction. In this case, the BFS parts can be removed by demolition of connected elements (Fig 15) (Durmisevic, 2006).

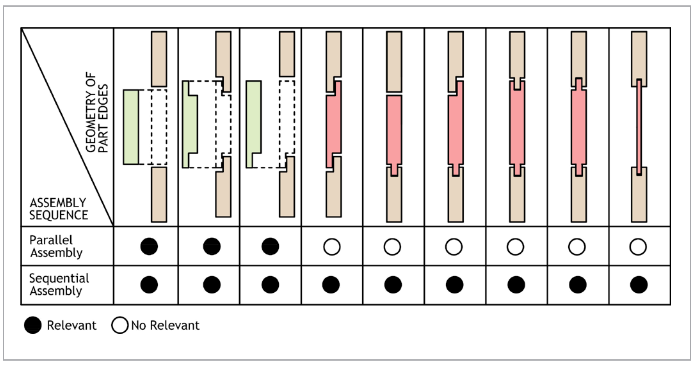

Fig. 15

Relationships between assembly sequences and geometry of BFS part edges

The parts of open BFS mostly have the simple geometry of edges and parallel (independent) assembly/disassembly sequences. Closed systems are often include stuck and massive parts, and accordingly with sequential (dependent) assembly sequences. An important goal of the design for disassembly is to reduce the number of assembly sequences, especially during replacement procedures.

Connections of BFS Parts

The design of connections is one of the most important and vital considerations of designing for disassembly. In general connections between the BFS parts can be divided into three categories in terms of how they interface with parts (Morgan and Stevenson 2005, Durmisevic 2006):

DIRECT CONNECTIONS: A direct connectors usually interlock or overlap with the BFS parts, which can make disassembly difficult due to the assembly process. In this way, the geometry of the BFS part edges forms a complete connection. The disassembly of overlapped connections depends on the type of material used in the connection, assembly sequences, hierarchical position of the BFS parts, and their relations with other parts. The BFS part edges are shaped specific and differently in an interlocked connection. In this case, the shape of the edges allows only for sequential assembly and this complicates disassembly process.

INDIRECT CONNECTIONS: Additional accessories are used to form the connection in an indirect connection. The accessory is inserted into the BFS part, or applied external side of that part. Indirect connectors are usually easier to deconstruct because they are interchangeable and independent from the façade parts. But, dismantling of such connections may be difficult because of the sequential assembly sequences.

INFILLED CONNECTIONS: Infilled connectors such as glued or welded connectors can be virtually impossible to disassembly unless the filler is very soft, such as lime mortar. In an infilled connection, assembly process of BFS parts is labour intensive.

Two key criteria for designing connections which can be disassembled while maintaining the integrity of all BFS parts are:

- Avoid interpenetration of connectors with the BFS parts.
- Adopt dry jointing techniques in preference to chemical jointing.

The type of connection may be used between BFS parts will determine whether or not it can be successfully disassembled (Table. 1).

BFS parts joined by simple mechanical and dry jointing connections (using screw, bolt, nail, etc.) may allow disassembly without the destruction of other parts associated with renovation, and support reconfiguration of the BFS without demolition waste. Screws and bolts allow for ease of disassembly as opposed to friction nails. Where nails or bolts are used with connectors, this may allow for fewer nails and therefore less damage to BFS parts. Mechanical joint connections of BFS parts may stand for the BFS that is technologically flexible. Technologically flexible system supports technological innovation by exchangeable parts at the all levels of the system and hinders technological obsolescence. Using mechanical connections means adhesives and chemical means of fastening are avoided to construct details with parts that can be disconnected for disassembly. Chemical and wet connections (mortar, resin bonding, adhesive, etc.) are fixed two joined parts permanently and essentially prohibit the reuse of parts.

Table 1

Connection Alternatives (Adapted from Morgan and Stevenson 2005)

TYPE OF CONNECTION	ADVANTAGES	DISADVANTAGES
Screw Fixing	Easily removable	Limited reuse of both hole and screws, cost
Bolt Fixing	Strong, can be re-used a number of times	Can seize up, making removal difficult, cost
Nail Fixing	Speed of construction, cost	Difficult to remove, removal usually destroys a key area of element
Friction	Keeps construction element whole during removal	Relatively undeveloped area, poor choice of fixings, structurally weaker
Mortar	Can be made to variety of strengths	Mostly cannot be reused, unless clay, strength of mix often over specified making it difficult to separate bonded layers
Resin Bonding	Strong and efficient, deal with awkward joints	Virtually impossible to separate bonded layers, resin cannot be easily recycled or reused
Adhesives	Variety of strengths available to suit task	Adhesive cannot be easily recycled or reused, many are also impossible to separate
Riveted Fixing	Speed of construction	Difficult to remove without destroying a key area of element

Durable components which can be reused should be specified in a design for disassembly. The edge geometry of BFS parts dictates the feasibility and sequence of disassembly. As well as the connectors, it is important specify the BFS parts with durable edges.

Connections define the degree of freedom between the BFS parts, through designing edges and connection type of BFS parts (Fig. 16) (Durmisevic, 2002).

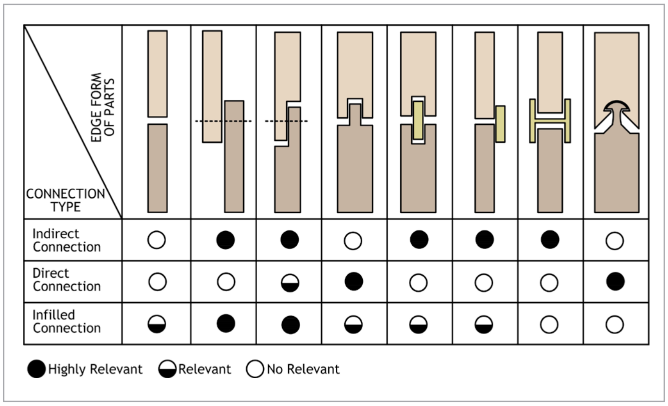

Fig. 16

Relationships between connection type edge form of BFS parts

Recovery Potentials of BFS Parts

There are several strategies for the recovering of a building system and its parts at the end of its life cycle, from complete relocation and reuse, to part recycling or incineration for energy. The recovery strategies for BFS parts, called recovery scenarios or more appropriately named end of life cycle scenarios can be presented as follow (Morgan C., Stevenson F., 2005):

_ BFS element reuse.

_ BFS component reuse.

_ BFS material recycling and reprocessing.

Recovering the façade elements by end of life cycle scenarios, the façade components or the façade materials can reduce the environmental impact of a façade part by reinvesting the materials and energy originally involved in its manufacture, and preventing additional hazardous emissions (Crowther 2005) (Fig. 17).

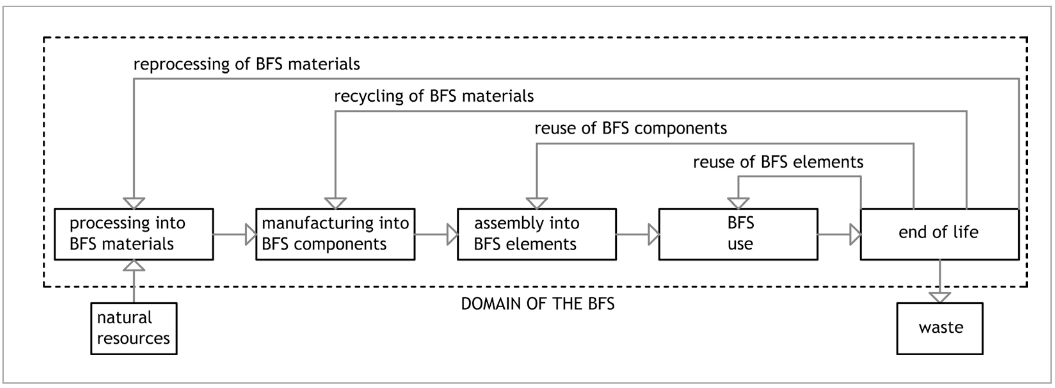

Fig. 17

Possible "end of life cycle scenarios" for BFS (Adapted from Crowther, 2005)

Reuse strategy is the process in which BFS part removed from its original location and used it again at another location. For example, a window removed from a house will be reused as functioning window in another project (building). Reuse is based on prolonging the life of the BFS or its parts by dismantling the part at the end of its life cycle and reusing it in a new combination (Durmisevic and Breouwer, 2002). Reuse process allows using a valuable BFS part more than once. The part may be used either in the same configuration or in a new configuration. This process may be required cleaning, repairing, replacement, transport, relocation, reconfiguration, etc. of BFS parts. Reuse process is required the BFS part has a longer life expectancy, and has still a value for another use. But if the quality of the part cannot be guaranteed for a relevant new life or a buyer is simply not found, reuse may not be an end of life cycle scenario. Reuse is the most desirable option because it is most effective in reducing the demand for virgin resources and reducing waste (Webster and Costello 2005). BFS parts should be checked to insure they perform as required for the new application. Especially load bearing parts should be thoroughly inspected and tested to insure that their reuse is feasible and safe. If a BFS part is not worthy enough for reuse and its value is worth more than the recycling value, it may be repurposed. Repurposing uses a part in a new way. Many of repurposed parts are complied with architectural details. These parts are often approved as the salvaged part. For example, a single window frame used as a picture frame, or a wood siding used as bookshelf, or a stone cladding panel used as a floor finish.

Recycle is the process in which BFS parts break down into raw materials so that they can be processed into BFS materials or manufactured into BFS components (Converting a scrap steel profile or panel into a new steel profile or panel for reuse). If a BFS part is not worthy enough for reuse and repurpose, it may be recycled. Many BFS parts that cannot be removed in large enough sections or pieces can typically still be recycled. For example, the reuse of gypsum board or chipboards is almost nonexistent, as well as the pieces of them can be recycled. Load bearing parts unsuitable for reuse may be recycled. For example, a carrier steel frame that does not pass testing for reuse could be recycled. Recycling is a common strategy because it requires relatively little time and only small investments. In the recycling process, a used BFS part is destroyed to manufacture a new similar or different part. Obsolescent or waste parts are not always able to recycle the same function or value. There are two different type of recycling strategies: upcycling and down cycling (Kibert et al. 2000). Upcycling means converting waste materials or useless products into new materials or products of better quality. Upcycling maximizes the lifecycle of raw materials (A lumber can be upcycled into more valuable items, such as custom cabinetry or furniture). Downcycling means converting waste materials or useless products into new materials or products of lesser quality and reduced functionality (A decayed timber BFS part can be used into the production of particle board, oriented strand board or mulch, and a degraded concrete part can be converted into coarse aggregate or land filling).

The reuse of a BFS part has the added advantage of requiring less energy or new resource input during the life cycle of it than the recycling of a BFS part. Therefore, a BFS must be better designed for the reuse of its parts rather than simply the recycling them. In reality it may be advantageous for BFS to be designed for recycling since the future reuse scenarios the BFS cannot be accurately predicted decades before eventual deconstruction. The effectiveness of recovery potentials of a BFS is dependent on BFS design for deconstruction. A number of design principles and strategies (mentioned in section 2) which have considerable influence upon obtaining recovery potentials are important to be considered in the BFS design for deconstruction process. The DfD principles/strategies can assist designers creating BFS for effective recovery potentials and deconstruction. Some of these design principles have more relevant to the

Table 2

Recovery potentials of common BFS parts

BFS PARTS	REUSE	RECYCLING
Precast concrete component/element	●	●
Modular AAC block/panel	●	●
Masonry block with dry connection	●	●
Masonry block with lime mortar	●	●
Stone cladding panel	◒	●
Lumber component	◒	●
Engineered timber panel	●	◒
Wood framing panel	●	◒
Timber siding board	●	●
Light weight steel framing panel	●	●
Metal cladding component	●	●
Metal profile component	◒	●
Plastic profile component	◒	●
External door/window element	●	●
Insulating glass unit	◒	●
Plastic sealing strip	○	●
Screw, bolt and nail fasteners	○	●
Loose insulations	●	●
Rigid foam insulations	◒	◒

● High potential ◒ Low potential ○ No potential recovery potentials than others (Crowther 2005).

Concrete, masonry, timber and metal are the basic construction materials and all have potentials for reuse and recycling. Glass and plastics tend to have limited reuse potential, and are generally more suited to recycling (Morgan and Stevenson 2005, Guy and Ciarimboli 2007) (Table 2).

Although concrete constitutes a large proportion of construction waste, there has been little reuse and the majority being downcycled for low grade applications. Precast concrete BFS components and elements have the potential for reuse based on the connection types and the dimensions. Connections made from stainless steel and removable fasteners will be both durable and allow disassembly. The majority materials of concrete components (sand, rock, cement and steel) come from nontoxic and readily available materials. Therefore the recycling of concrete BFS parts as concrete pieces and steel reinforcing is common.

Autoclave aerated concrete can be used to make blocks and panels, and reinforcing can be added into the molds before the slurry is poured. Components (wall block and panel) made from AAC have been reused, and have recycling potential, because they comprise nontoxic materials.

Because of absence of mortars and additional reinforcing means, modular masonry wall blocks (stone, concrete and clay) use a dry connection (screws, steel ties, dry stack interlocking concrete units, etc.), are readily demountable and reusable. The use of cement for binding rather than a lime mortar is a great limitation on the reuse of masonry blocks, because it is often stronger than the masonry blocks. Masonry blocks are highly durable and easily reusable BFS parts if used with a lime based mortar. Reused masonry blocks used with a lime mortar, are optimal when compared to new one, although reuse of blocks for structural purposes can be problematic. Absorption of existing mortar may inhibit a good bond for new mortar.

The reuse of stone cladding panels can be problematic unless the joints and connectors are carefully designed for disassembly.

As long as it has not been contaminated with toxic preservatives, paints, or adhesives, wood can be reused, recycled. Woodworks should ideally be finished with wax or natural stains rather than paint. Solid lumber of sufficient dimension is a highly flexible BFS part for reuse and remanufacturing, as it can be cut and worked to make new sizes and shapes without loss of its base properties. Lumber used in light wood framing wall system, is problematic for disassembly often due to the use of a large number of nails and many small increments of material of relatively small dimension. Clips, angles and plates, bolts, double headed nails, are means to make the wood parts easier to disassemble.

Engineered timber BFS parts use minimal materials while maintaining a high degree of quality and strength characteristics. Engineered parts are problematic for recycling because of the use of adhesives, binders and resins have impacts for human and environmental health. Engineered timber parts have potential for resource utilization and high tolerances which can create more certainty for reuse as load bearing BFS parts.

Wood frame wall panels allows for the reuse potential of entire panels depending on the connection and dimensional suitability. If infill unit of wall panel comprises toxic adhesive and resin materials, the recycling can cause problems.

Timber siding cladding allows for the replacement of individual boards without impinging adjacent boards, thus may be good component for DfD. Horizontal lapped siding is limited the reuse potential by the layering which laps each piece above the piece below. The intricacies of the siding profiles such as tongues, grooves and chamfers are easily damaged during removal and are rarely feasible to remill. To secure the profile the first inclination is to replace nails with screws that can be removed. But screws are far from the ideal removable fasteners in construction because the screws leave a hole or defect in the wood after removal. A removable connection can be provided by a fastener system with clip which is noninvasive and easily removable. It has a double bend, one bend to capture and hold the bottom of a siding board, and the second bend to secure the top edge. Another removable connection type uses unmilled boards held in place by a channel or similarly shaped reglet at the ends of the boards. The boards are full dimension with minimal loss of material from original milling, or from remilling for future reuse. Painting timber siding greatly limits its reuse and recycling potential while increasing its life.

Light weight steel framing wall system may be an alternative to conventional light wood framing wall system. Steel components can be disconnected more readily than wood components and the homogeneity of the framing and connectors also allows it to be recycled without disconnecting the individual framing parts.

Metal (steel, aluminum, zinc, etc.) cladding is a suitable component to deconstruction, because it is a sheet material with light weight and uses typical mechanical fasteners. The vaious alloy cladding types can be recycled or reused, although reuse may be problematic given the penetrations caused by the connecting screws. The use of screws allows for relatively efficient disassembly using simple tools.

Many external door and window systems are usually prefabricated elements and designed for ease of dry/mechanical connections and possible removal. However, this ease of removal can be compromised by flashing and external finishes that overlie the window/external door flanges and prevent ease of removal without damaging the adjacent finish parts. If suitable flange details, allow for ease removal, are developed, windows and external doors would be highly reusable elements. Because PVC, steel and aluminum materials have potential for recycling, window profiles made from these types of materials may be recycled into profiles or pipes. Paint finishes on the steel or aluminum profiles inhibit recycling of these parts. Plastic sealing strips used in the window/external door system for weatherproofing, are not safe to be reused because they may not have the required performance for second use.

In critical applications, fasteners should never be reused. But when the reassembly application is not critic, and the bolt fastener has not been stressed past its yield point, it can be reused. Screws and nails are not safe to be reused.

Cotton, cellulose, fiberglass, and mineral (slag, rock) wool batt or blown insulation can be readily removed in a deconstruction process, and reuse because they are not adhered to the adjacent components. Fiberglass is problematic due to its fiber as a potential health issue, but all of these forms of insulation can be recycled. Rigid foam insulation such as EPS and XPS, are cut into panels and used into external walls or over wall core and under the exterior finish. When removing the insulation panels in a deconstruction process, their selfsupporting form will allow them to be removed intact for reuse. These materials are also recyclable, but EPS uses pentane as a blowing agent, and XPS uses variants of ozone depleting chemicals. Rigid insulation systems often bond mineral render finishes to the insulation behind, making reuse impossible.

Conclusions

Because of physical deterioration, aesthetic obsolescence, and technological obsolescence, the service value of the BFS comes down, therefore it and its parts may constantly be waste disposal. We couldn't stop factors which cause deterioration and obsolescence of BFS, but we could be accommodated them, through BFS for Deconstruction. Deconstruction of the BFS is related to the ability of the BFS parts to be easily disassembled, replaced, reconfigured, and reused.

Conventional Building façade systems are usually not designed for deconstruction. For that reason at the end of life cycle of BFS or its parts, demolition and waste occurs. In order to increase the deconstruction capacity, BFS has to focus on the number of design considerations that will help providing disassembled BFS whose parts could be easily replaced reconfigured, reused and recycled. This paper has identified five major design considerations for BFS for Deconstruction such as: Functional Decomposition of BFS, Systematization of BFS Parts, Assembly and Disassembly Sequences, Connections of BFS Parts, Recovery Potentials of BFS Parts.

BFS can be structured following the pattern of functional decomposition into the sub functions, such as resistance to agents, admitting air and light, and access to building, and then sub sub functions such as, support, control, finish and integration.

The systematization of BFS deals with hierarchical organization of BFS parts according to desired functionality and arrangement and integration of the parts into specific physical level. The systematization should start with functional decomposition and its allocation through different BFS parts. According to their primary functions in the BFS, physical parts of BFS may be organized in three main groups as: façade elements, façade components and façade materials. BFS is composed of three main façade elements, such as, external wall, window and external door. An external wall element in a BFS may be configured using the following façade components: Carrier, finish, insulator and supplementary. Window and external door elements in a BFS are generally an assemblage of following components: Immovable Frame, Movable Frame, Infill Unit, Sill, Weatherproofer and Supplementary.

Assembly/disassembly sequences of BFS can create dependencies between BFS parts by giving them ability to be dismantled. Parallel assembly sequence can speed up an assembly/disassembly process. Assembly/disassembly sequences can be affected by the geometry of BFS part boundaries. The simple geometry of BFS part edges and independent assembly/disassembly sequences, are main characteristics of open (demountable) BFS.

The interfaces of BFS parts define degree of freedom between BFS parts, through design of part edges, and connection type. The connections types of BFS parts influence assembly/disassembly sequences. Simple mechanical and dry jointing connections may allow disassembly without the destruction of adjacent parts, and support reconfiguration of the BFS without demolition waste. Chemical and wet connections are fixed two joined parts permanently and essentially prohibit the reuse of BFS parts.

Deconstruction of a BFS is a demolition approach where the BFS is carefully and methodically disassembled and decomposed, so as to recover as many system parts as possible. There are several strategies for the recovering of a BFS and its parts at the end of its life cycle such as, reuse, and recycling/reprocessing. Reuse strategy is the most desirable option because it is most effective in reducing the demand for virgin resources and reducing waste. If a BFS part is not worthy enough for reuse, it may be recycled. Recycling is the common strategy because it requires relatively little time and only small investments. The reuse of a BFS part has the added advantage of requiring less energy or new resource input during the life cycle of it than the recycling of a BFS part. Therefore, a BFS must be better designed for the reuse of its parts rather than simply the recycling them. The DfD principles/strategies can assist designers creating BFS for effective recovery potentials and deconstruction.

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