

# ADAPTABLE RAISED FLOOR SYSTEM

## FOR OPEN BUILDING

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### ABSTRACT

*Open building are concept that aim to create high quality buildings with increased flexibility for mass-customization and increased adaptability for future-renovation. However, there are still not much Open Building project in our industry. Therefore, In this paper, as part of the research of the open building concept, the technical solution for the plumbing system in multifamily apartments are discussed. has the objective of designing a typology of an adaptable floor system that can be widely applied in the construction industry in the renovation project to reach the maximum level of adaptability in floor layout design.*

**Keywords:** *Open Building Infill System, Vacant Office Building Adaptive Reuse, Plumbing System, Multifamily apartment*

### I. INTRODUCTION

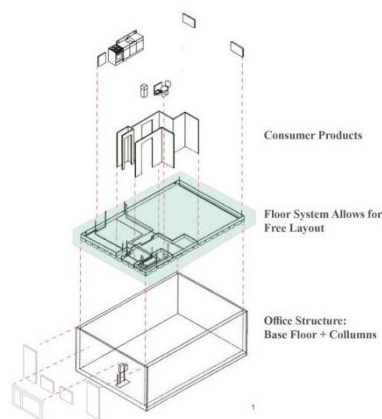


Figure 1 (Illustrated based on Habreken.1992 )

The concept of Open Building(Fig 1) was first articulated by the Dutch architect John Habraken in 1960s. In an open building, the residents' s personal preference can be realized in different scale with several detachable sub-system of the whole building. The concept will also benefit in the sustainable perspective as the life cycle are varies for different sub-system and part of them need to be renovate in different period. And the concept not only works in new building but also works in renovation building based on its simple principle that the sub-system can be replaced while the structure as the support system is remained.

In the design context, Netherlands has a serious problem of office vacancy and the problem is even severe in Amsterdam. While the design problem focus on the adaptive reuse of office

building into dwelling project, the research paper can dive into the technical solution that based on the design problem.

## II. RESEARCH METHOD

The objective of the research paper as presented is to develop possible alternative prototypes for adaptable floor system that can be applied in Open Building which improves the mass - customization of floor layout design and adaptability for future renovation work.

Based on the overall design question, the research questions and the derived sub-questions will be analysed and answered in this paper.

Over all design question: How to implement the concept of Open Building to transform vacant office building into a sustainable dwelling project ?

Research Question: What can we learn from precedents solutions and products to elevate the design of Open Building plumbing solution when transforming office building into multifamily apartments to reach the maximum adaptability in floor layout design ?

Sub- Research Question:

- 1) What are the current common plumbing solutions in Open Building project and which one could be best fit into the context of the design project?
- 2) During the transformation process from office space into multifamily apartment, what is the technical advantages and limitations?
- 3) Which design aspect should be considered in the comparison between previous solutions? And what kind of criteria should be considered under each aspects?
- 4) What can we learn from the cross case study to elevate the current solutions?

The Research Questions will be answered by dividing the research paper into three phases, each with its own focus. The research framework is illustrated in Figure2

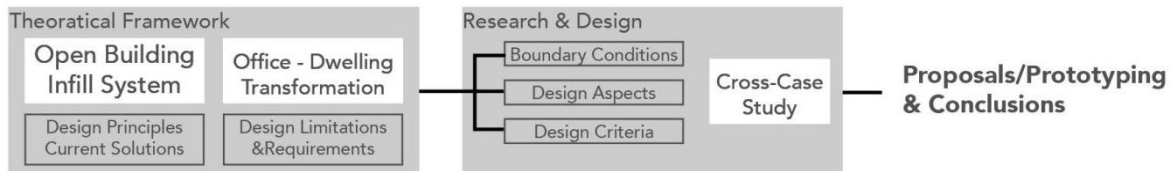


Figure 2 Research framework (Own ill, 2018)

In the first part, a theoretical framework will be built by reviewing the literature and case studies of built project that concerned with Open Building Plumbing System Solution. The design limitations during the renovation process will also be studied to understand the technical design context. In the second part, different design aspects and criteria(Fig) will be applied in the comparison to understand which solutions or products meet the requirement most. The prototyping and proposals are based on the cross case study process.

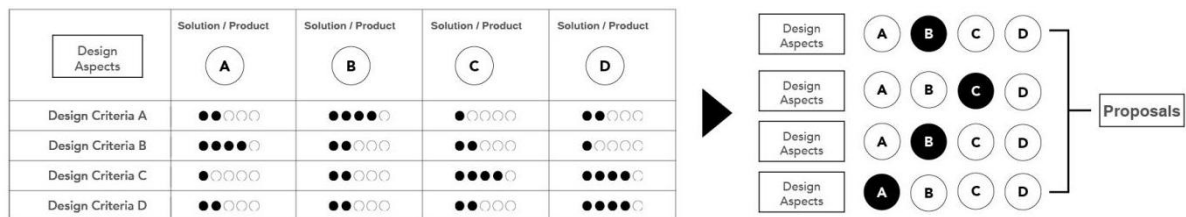


Figure 3 Cross case study method (Own ill, 2018)

### III. RESEARCH AND FINDINGS

#### 3.1 The technical limitations in office renovation.

In the design context, standard office building built after 1950 are chosen to be the target group for renovation. In most of the vacant building there are a shared typology. The buildings are stabilised by a central core of stairs and elevator shafts, sometimes with extra structure support elements on the facade.

- Floor penetration limitation: Most of the office building are built by prefabricated concrete floor slab and made it difficult to penetrate to add vertical shaft.
- Floor height limitation: The Dutch housing requires 2.6 meters minimum free floor height. Any renovation work about the floor should take this in mind.
- Acoustic Limitation : The office sound insulation requirement is lower than housing project, therefore, extra insulation between different unit and floors is needed. A floating floor or ceiling are the most common solution. (Remoy, 2010)

#### 3.2 Precedent Open Building Plumbing Solutions

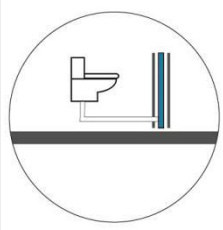
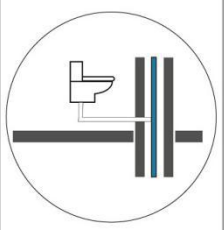
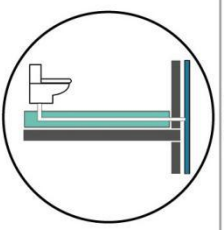
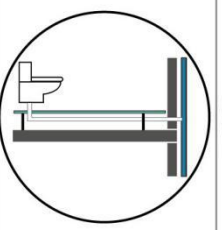
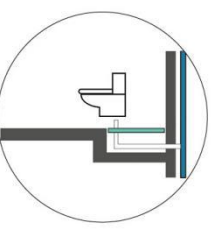
				
1 Cabinet	2 Fixed Shaft	3 Matura System Tile	4 Raised Floor	5 Floor Trench

Table 1 Open Building Plumbing Solutions

Five different systems in built Open Building plumbing solutions are discussed to find the most appropriate choice for the design context. There are four pre-conditions that based on the technical limitation of the renovation project: 1. Floor penetration is not possible, any change to the original structure should be limited. 2. The solution should provide as much flexibility as possible of the floor plan design in order to allow the residents to customize their unit. 3. The space use for the plumbing system should be limited due to the limited height of the office space. 4. The system or solutions should be easier to renovate with a clear management of pipe distribution.

In the above five solutions, (Table 1, detail explained in Appendix 1), the Matura System and the raised floor solution are chosen for its possibility for the lowest floor height, convenient maintenance and clarity in the system.

In the next section, seven products and floor solutions (Table 2) which shared the same principle of the two chosen solutions are selected to have a further cross-case study based on the design principles and criteria of the literature research.

### 3.3 Cross - case study of precedents floor system and products

#### 3.3.1 Design aspects

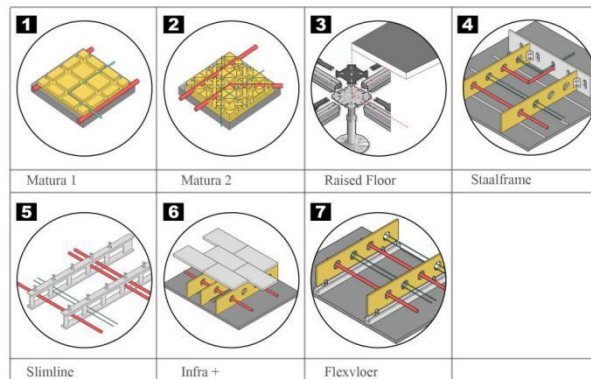


Table 2 Seven Floor Systems and Products

#### Cross case- study and methodology

In this section, four design aspects are studied based on the chosen floor product in order to understand the floor system design logic. In each aspect, there are several matching alternative solutions which will be compared in several criteria. Proposals and prototyping will be generate based on the conclude solutions.

The following four design aspects will be studied from different perspective.

#### 1 Connection: floor - walls

- thermal quality : the connection design should meet the thermal insulation requirement of the renovation project
- acoustic quality : sound insulation should meet certain standards between each unit and between each room
- finishing : the connection design should meet certain aesthetic value
- disassembly: the connection should be designed to make the future renovation work easier and connection component can be reusable

#### 2 Support

- structure safety: the support element should strong enough to carry the load of the upper space
- amount of elements : for the desired situation, the element number should be limited to minimize the on-site building activities
- dis/assembly: the support element should be dis-assembled easily to reused again

#### 3 Pipe Flexibility:

- all the pipes should be easily reachable for future change
- the support of the system should remain the same as much as possible during renovation process

#### 4 Installation:

- installation should be performed by less trained construction workers
- dis / assembly can be done by one person each time

### 3.3.2 Case study findings

#### 1. Connection : floor - wall

thermal quality	●●●●○	●●○○○	●●○○○	●●○○○
acoustic quality	●●●●○	●●○○○	●●○○○	●●○○○
dis/assembly	●○○○○	●●●○○	●●●○○	●●●○○
adaptability	●●●○○	●●○○○	●○○○○	●●●○○
conclusion	●	●	●	●

Table 3 Connection solution (Own ill, 2018)

- dry seals : by using a dry seal in the horizontal joint, the following benefits can be achieved : easy for dis-assembly and components could be reused, changes in the maintenance on the building could be simple achieved.
- structure safety : the indoor partition wall is best to installed on support structure of the floor system to balance the need of structure stability and the pipes layout freedom
- thermal insulation : in case there are pipe needs to run into the wall, thermal insulation should be designed and implemented together with the support element.

#### 2 Support

amount of elements	●●●●○	●●○○○	●●●●○	●●○○○	●●●●○
installation	●●●○○	●●●○○	●●●○○	●●●○○	●●●○○
adaptability	●●●○○	●●●○○	●●●○○	●●●○○	●●●○○
conclusion	●	●	●	●	●

Table 4 Support Solution (Own ill, 2018)

- amount of elements : there are several types of support element in each system maily serves as three functions: 1 connect to the structure floor; 2 adjust height to ensure a flat surface in renovation project; 3 support the pipes; when selecting component, function 1 and 2 should be combined in order to achieve a minimum element number
- installation : there are 2 types of connection for the support and the structure floor : 1 the support element is bolted or glued to the structure floor, but gluing make it difficult for future adjustment; 2 the component is laid loosely on the structure floor which decrease the structure safety. Therefore, bolted connection proved to be the best solution.

### 3 Pipe Flexibility

installation	● ● ● ● ● ○	● ● ● ● ● ○	● ● ● ● ● ○	● ● ● ● ● ○
pipe numbers	● ● ● ● ● ○	● ● ● ● ● ○	● ● ● ● ● ○	● ● ● ● ● ○
adaptability	● ● ● ● ● ○	● ● ● ● ● ○	● ● ● ● ● ○	● ● ● ● ● ○
conclusion				

Table 5 Pipe distribution solution (Own ill, 2018)

- all the pipes should be placed parallel to each other and on one surface: In the upgrading design from Matura 1 to Matura 2, the main issue that solved is to put the drainage pipe on the same layer, reachable from above by people because during the construction process of Matura 1, people found it a bit trouble if they want to change the bottom pipe layout, they have to open the Matura Tile again. Also in the other system, pipe are intertwined together sometimes, which decrease the clarity of the whole system. Therefore, pipes are suggested to put on the same surface height instead of overlay each other.
- support element design : in raised floor system, stringers are added to provide stable support for the upper sub-floor, in that case, construction workers have to remove the stringer to change the pipe layout.
- angles of 45 degree and 90 degree as common angle of pvc fitting pipe component, the two angles will be chose to combine in the component design to reach maximum distribution freedom.

### 4 Installation




Table 6 Installation solution variation (Own ill, 2018)

In the above table, 3 types of installation method for different system is illustrated by process.

In the first solution(concept of Matura Tiles), the assembly time and installation time is reduced for the product is designed to be a one-piece unit . But further reinforcement for the component is needed and this will cause a increase of installation time.

In the second solution(Raised Floor,), aluminum pedestal are placed first on a 600m\*600mm grid, then the pipes are placed between the grid. Stringers might be added to increase the stability of the floor system and a top floor layer is added in the end. Stingers might increase complexity in future renovation work as pipes are placed under the stringer grid.

In the third solution (staalframe, infra+, slimline, flexvloer), stripes are first installed on the ground and then panels are set up. Pipes need to run through the holes on the panels which cause the installation process more complicated than the above 2 methods.

### 3.4 Proposals and prototyping

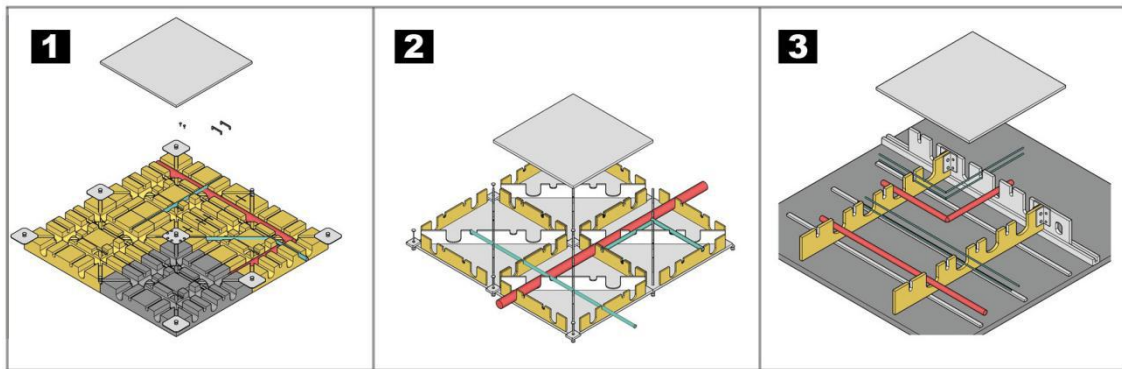


Table 7 Prototypes (Own ill, 2018)

Proposals & design suggestions:

- Dimensions : standard dimension of 600mm \*600mm will fit most of the top floor panel size
- Accessibility: pipes should be accessible from top during the installation process and future renovation. The support element design should allow the pipes be directly placed in the open grooves instead of placed through different holes on the support structure.
- Flexibility:

1 height adjustment : aluminum pedestals and different gasket can be applied to the support element for the adjustment of different floor height and the pipe slope

2 pipe layout adjustment : pipes should be directly pulled in or out from top with open grooves

## IV.CONCLUSIONS

The research is aiming at a approachable solution based on current existing products available on the market. In the first part of the research, technical limitations in the design context are listed to generate a boundary condition for further design. Several plumbing solutions are analyzed and compared in order to find the best solutions. And the second part focus on the exiting product for different raised floor system and open building floor product to understand the design principle of the floor system to generate a better solution to fit into the design context. With a cross-case study, four design aspects are evaluated by several criteria which gives direct design input of the prototyping. Three prototypes are proposed in the last part as a result, they are not totally brand new design, but will act as a smart combination of previous solution. To

achieve a plausible final solution, future research must be carried out to test the prototypes. Research about the technical details during the manufacture process, bathroom finishing solutions and floor finishing should be done.

## **V. REFERENCES**

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## APPENDIX 1

### PRECEDENT OPEN BUILDING PLUMBING SOLUTIONS

The appendix will serve as a support to understand the plumbing solutions by comparing different conventional practice in built Open Building project. According to the general principle of Open Building, the following pipe routing strategies are classified by position of water supply and drainage piping between different fixtures , sub-system and the vertical drainage pipe as part of the base building. (Table 8 )


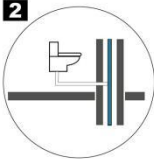
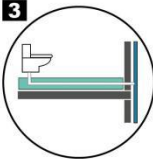
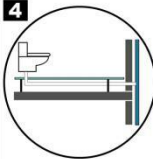

		<b>1</b> 	<b>2</b> 	<b>3</b> 	<b>4</b> 	<b>5</b> 
		Cabinet	Fixed Shaft	Matura System	Raised Floor	Floor Trench
Position	Supply pipes	in floors and walls or ceilings	in floors and walls	in Matrix Tiles	in hollow raised floor	in floor trench or raised floor
	Grey drainage pipes			in Matrix Tiles		in floor trench with floor covering
	Black drainage pipes			in or between walls		
Slope (Min)	Grey drainage pipes	2%	2%	0	2%	2%
	Black drainage pipes	1%	1%	0	1%	1%
Space Needed		20cm extra wall thick and max 40cm floor height	20cm extra thick for the double wall	10cm height on the floor of the whole dwelling	max height 40cm for the raised floor	min height 40cm or more for the raised floor
Reference project		Tilla (1)	Solids (2)	Voorbrug Renovation Project (3)	Japan Dwelling	NEXT 21 (4)
Floor Layout Flexibility		●●●○○	●○○○○	●●●●○	●●●●○	●●●○○

Table 8 (Adapted from H.Qiong & K.Stephen,2011 )

#### Solution 1: Prefabricated Bathroom Unit “Cabinet Solution”

The dimension of the wall depends on the size of the ducts, and the organization of the piping system can be complicated due to other utility conducts ventilation system. The solution will cause a thicker wall system thus decrease the floor function area. Also there are less alternative products of bathroom unit on the market which limits the possibility of future renovation.

#### Solution 2: Fixed Shaft

Floor trench needs to be designed with the structure system in the beginning stage. The flexibility of floor layout is largely depends on the position of the shaft. In most of the built open building cases, the shaft was always placed in the center of the floor plan.

#### Solution 3: Matura System

In Matura System, water supply and drainage pipes are placed in grooves of Matrix Tiles installed above the structural floor and under the finishing floor. Apart from the benefit of allowing building owners to meet individual occupants’ floor plan layout preferences, the Matrix Tiles also reduces pipe maintenance and space rearrangement costs because access to neighboring spaces is avoided, sound isolation quality is also increased between different units.(drstephenkendall.com,retrieved: 2018,04,28)

## Solution 4: Raised Floor

Raised floor system are quite common in office building, data center and in dwelling projects of Japan. The under floor space is accessible for renovation and maintenance as the top finishing panels can be lifted easily. However, the raised floor often take higher space than the other system.

## Solution 5 Floor Trench

Floor trench needs to be designed with the structure system in the beginning stage. All the pipes and cables will be distributed in each unit, this allows for large-scale rearrangement of water related facilities. (H.Qiong & K.Stephen,2011)

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1. Tila(Fig4 ): The dwelling project is located in Arabianranta, Helsinki, built in 2011. The neo-loft concept is based on an open construction system: within the available building frame the resident determines and builds the required subdivisions. The dimensions and structure of the apartments are designed to reach a maximum flexibility for residents to customize and build individual rooms.

The bathroom unit were prefabricated off-site. The outlets for the kitchen fittings are located on the main room side of the bathroom module which allows for different kitchen layouts. There is a thin floor slab under the bathroom unit to allow piping to be connected to.(drstephenkendall.com,retrieved: 2018,04,28)



Figure 4 Tilla (Kendall S,2017)

2. Solids(Fig5 ): The dwelling project is located in Amsterdam, Netherlands, built in 2011. The concept of Open Building is implement in the design phase for the structure of the building. The only fixed building element on the floor plan is the piping shaft that placed in the center of the building. Residents can choose to install a raised floor to hold the space for plumbing system and floor heating system or just have the bathroom and kitchen close to the piping shaft.(drstephenkendall.com,retrieved: 2018,04,28)



Figure5 Solids (Kendall S,2017)

3. Voorbrug Renovation Project(Fig6 ): The dwelling project is located in Voorbrug, Netherlands, finished in 1993. The dwelling project was renovated by a pioneer technical solution of the infill system.

The Matura System was introduced in this project: a thin layer of floor “tiles” were placed on the structural floor to create a zero-slope plumbing system. The construction process can be done one - dwelling - at - a - time to make the organization more efficient than the conventional renovation process.(Kendall S,2017)



Figure6 Voorbrug Project (Kendall S,2015)

Next 21(Fig7 ): The mixed-use project is located in Osaka, Japan, built in 1993. It serves as a continuing experiment with energy systems such as hydrogen fuel cell technology, mutable interior fit-out components, adaptable facades, mechanical systems and introducing nature into urban environments. 13 architects was invited to each design the fit-out of a dwelling for the first original building. Other architects have since been hired to redesign individual dwellings in the building, experimenting with new infill components and processes.(Kendall S,2017)



Figure7 Next 21 Project (Kendall S,2017)

## Appendix 2

### Information about chosen products and floor systems

#### 1 Matura 1

The Matura System offers a new way of distribute ducts and cables in a dwelling unit. Each gray-water fixture is connected by its own drain line (no branching) to a manifold at the vertical gray-water pipe shaft , all drain lines are of the same diameter and can be up to 10 meters in length with 5 elbows, therefore it allows the gray-water drainage piping to be securely laid in the larger grooves of the Matrix Tile with no slope. (Kendall, 2015)

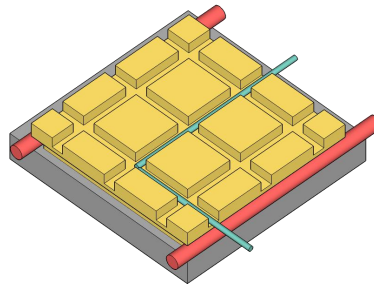


Figure 8 Matura 1 Floor System Concept (Own ill, 2018)

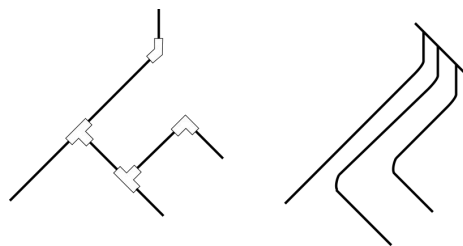


Figure 9 Pipe distribution concept: Left :Common Solution with branching off

Right: Matura System, each gray-water fixture is connected by its own drain line (no branching)  
(Own ill, 2018)

#### 2 Matura 2

The Matura 2 system is an elevated design based on the Matura 1 system. Standard polystyrene tiles (10cm thick with grooves on the top, adapt from the previous groove layout) are laid loose on the floor, piping is laid out in the grooves and then the floor is closed with a fire-proof floor layer. (Kendall, 2015)

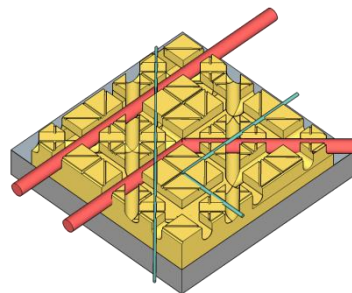


Figure 10 Matura 2 Floor System Concept (Own ill, 2018)

#### 3 Office raised floor

Raised floors are widely used in modern office buildings, and in specialized areas such as

command centers, IT data centers and computer rooms, where there is a requirement to route mechanical services and cables, wiring, and electrical supply.

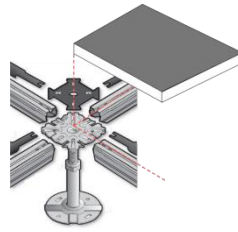


Figure 11 Raised Floor System Concept (Own ill, 2018)

#### 4 Staalframe

Staalframe offers advantages of saving the assembly time and installation costs compared to traditional construction. In the floor system, there are recesses for the transit of pipes. Depending on the building's physics requirements for noise and fire the floors can be made suitable for the specific project. The system takes the advantages of dry building. It involves a shorter construction time, it is dismountable and the steel is 100% recyclable. With dry outfitting, the system is also very flexible when it comes to renovation and changing the pipe network. The hollow space in the floor is at least from the bottom accessible, where depending on the desired fire resistance, one or two plasterboards are available applied as a ceiling. When using a dry top floor, the pipes are also accessible from the upper side of the floor.(Boon, 2007)

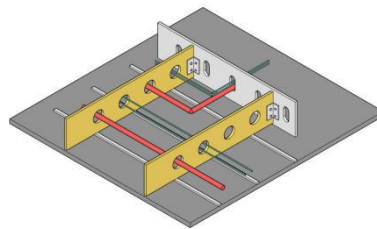


Figure12 Staalframe Floor System Concept (Own ill, 2018)

##### - architectural features

Structural strength maximum span is 7.2 meters

Weight of beams <80 kg / m<sup>2</sup> (total depending on the finishing floor)

Height profiles 200 - 350 mm (excluding finishing above and below the floor)

##### - building-physical properties

Noise: depending on the function and the requirements, an optimum can be achieved for every situation

Fire: a single plasterboard 30 minutes, a double 60 minutes.

##### - pipe flexibility

gas, water, electricity, waste water drainage, pipeline to 110mm diameter, mechanical extraction components can be disassembled and reused; steel component is also 100% recyclable

with dry finish on the floor, the pipes can be reached from above and below

##### - finishing options

conventional sheet materials, for example cement-bound fiberboard, profiled steel sheets

with cast floor or with dry finish and plasterboard on the underside

#### 5 Slimline

The Slimline floor system is the integral combination of ceiling, installation space and subfloor. The solution is based on supporting steel beams, which contain a standard pattern of openings, integrated in a concrete ceiling slab. The beams and the slab are combined in prefabricated elements which are topped with the subfloor of choice. The system is thinner and lighter than conventional floor systems, facilitates a fast building process and offers permanent adaptability of the building installations. Slimline makes it possible to integrate construction and installations by utilizing the installation space between ceiling and subfloor. A Slimline floor element is comprised of steel beams (IPE) and a concrete slab. (Retrieved from: <http://www.slimlinebuildings.nl/NL/english>)

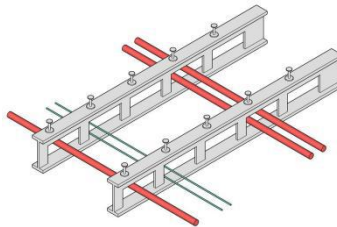


Figure 13 Slimline Floor System Concept (Own ill, 2018)

- architectural features

With a span of 4.4 m (max. Span 16.5 m);

Available element widths :2400mm, 2700mm, 3000mm

Height: 280 mm.

- building-physical properties

Sound: + 10 dB

Fire: The fire resistance is 145 minutes.

- Pipe flexibility

Climate pipes can optionally be poured in the concrete slab.

- finishing options

The raised floor type is based on steel profiles which are placed over the IPE profiles. On top of these profiles the standard 600 x 600 mm tiles are installed.

- Installation

A 16 mm deep Lewis® dovetailed profile, galvanised steel, reinforcement sheet with concrete screed is fixed to the top of the steel beams to create a floating subfloor. Access to the horizontal service voids is through specially installed access points (flexible access zones) in the finished subfloor.

## 6 Infra+

The Infra + floor (Figure14 ) was developed based on the idea that piping is independent from the supporting structure and in an attempt to reduce floor height, in combination with a dry construction method.

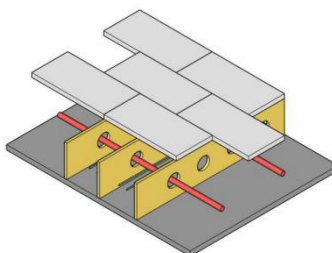




Figure 14 Infra+ Floor System Concept (Own ill, 2018)

The Infra + floor consists of a concrete slab of 70 mm thickness and a number of profiles with recesses, whose bottom has been placed into the concrete slab. The recesses make all kinds of desirable pipe run in the floor possible to reach a complete pipe flexibility. Rubber strips are applied to the steel profiled. With common plate material, the top floor can be removed relatively easily in parts, making the pipes easy to reach and to shift. With a flexible top floor, bathroom can be placed in anywhere on the floor plan and are also convenient to remove in future renovation. Also combination with underfloor heating is possible. (Boon, 2007)

- architectural features

With a span of 5.4 m (max. Span 14.4 m);

Weight: 300 kg / m<sup>2</sup>

Height: 280 mm.

- building-physical properties

Sound: practical values of + 10 dB for both air and impact sound.

Fire: The fire resistance is 145 minutes.

- Pipe flexibility

Drainage, water, heating, electricity, telephone wiring, computer network and ventilation

easy to incorporate into the hollow floor. A partially or completely removable top floor can be realized, so the below space is fully accessible.

- finishing options

A removable top floor is placed on top of the height-adjustable steel rails, which are fixed at right angles to the I-profiles.

- Installation

For the disk operation, the plates are mutually connected by means of welded plates. Also steel diagonals are placed on the steel profiles in the work. The floor is directly installed, no under stamping is required.

## 6 Flexvloer

The Flexvloer is a wooden system that was developed to give substance to the increasing demand for the life-course durability, flexibility and sustainability of residential and non-residential construction.

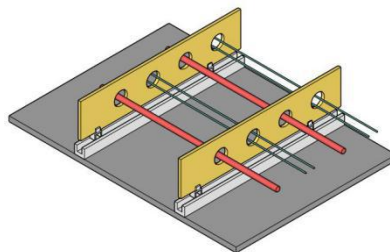


Figure 15 Flexvloer Floor System Concept (Own ill, 2018)

The load-bearing floor consists of ribs and floor slabs that are glued together to create a stiff floor element (rib cassette). With this floor element, the largest free spans can be up to 8000 mm. The Flex Floor is sustainably produced (wood, industrially made) and offers space to air, sewerage and other pipes that can also easily be retrofitted. (Boon, 2007)

- architectural features

height: 385 mm

width: 2400 mm (size-free)

length: 7000-8000 mm

-Pipe flexibility

All desired pipes and desired distribution equipment can be installed in the floor. The recesses can be fitted on a factory basis, and it is also possible parts in the factory. The floors are accessible from below and from above so that adjustments can be made later.

-Finishing options

Various floating screeds can be installed on the floor slab.

Appendix 3  
Proposals and Prototype for the Open Building Plumbing Solution (Table 9)

