Sustainable building components

The benefits of flexible installations

winkels

UNIVERSITEIT TWENTE.
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Sustainability is becoming a prominent issue in the 21st century. Global warming is coming and valuable materials are depleting. The construction industry is responsible for 30% of the CO2 emission and 66% of total waste. Improvements to the sustainability of the construction sector need to come quickly.

At the end of its life buildings get demolished. This is often not because the buildings are structurally deteriorated, but because they do not offer what the users need. Building installations are often the cause of this reduced functional lifespan. In order to reduce the material waste that demolition brings, and to accordingly reduce the negative environmental impact of buildings, the functional lifespan of the building should be lengthened to match its physical lifespan. This can be accomplished with flexible buildings. They can keep up with changing user requirements, by (dis)(re)assembling building components that need to be upgraded or replaced with new functionalities to accommodate the ever changing needs of the user.

IDF (industrial, demountable and flexible) building is a vision that encourages flexible building. It argues that building demolition can be reduced by designing buildings that are demountable. Other literature reveals that the accessibility and ability to be disassembled of building components are key to such a building approach.

This report described the development of the IDF bathroom. It is a modular bathroom that is developed according to the IDF building vision. The bathroom is designed to offer quick adaptability to the user’s needs. With it, the user can easily reconfigure the layout of his/her bathroom. In particular the design of the bathroom installations is elaborated. The report follows the design of the installations. It describes what the important design considerations are, and which design criteria the research upholds.

The results show that it is possible to design a flexible setup for the installations in the IDF bathroom. The bathroom consists of a metal frame to which detachable wall panels are attached. All the installations are located behind those wall panels. A variety of wall panels is available (toilet panel, shower panel, etc.). Each panel has a specific pipe layout. The interface between the wall panel and the IDF bathroom has been standardized. Except for the shower drain there are no major problems.

A lifecycle assessment of the IDF bathroom indicates that it can have less environmental impact than a traditional bathroom. This requires that 80% of the wall panels are reused. Future research is best focused on reducing the weight of the wall panels and of the frame.
**Samenvatting**

Duurzaamheid, of eigenlijk het gebrek daarvan, wordt langzamerhand een groot probleem in de 21ste eeuw. Het broeikasseffect groeit en onze voorraad waardevolle grondstoffen put uit. 30% van de CO2 uitstoot en 66% van de totale hoeveelheid afval wordt veroorzaakt door de bouw. Het is belangrijk om op korte termijn verbeteringen in duurzaamheid van de bouw door te voeren.

Het probleem dat de levenscyclus van een gebouw eindigt met zijn sloop. Dit wordt meestal niet veroorzaakt doordat het gebouw structureel achteruit is gegaan, maar omdat de functie van het gebouw niet aansluit bij de wensen van de gebruikers. Veelal wordt de beperkte levensduur veroorzaakt door verouderde installaties. Om de hoeveelheid materiaalafval te reduceren, en daarmee de negatieve milieuimpact te verkleinen, moet de functionele levensduur een gebouw worden verlengd zodat het aansluit bij de structurele levensduur. De oplossing voor dit probleem ligt bij flexibele gebouwen. Flexibele gebouwen kunnen worden aangepast zodat ze aansluiten bij de wensen van de gebruiker.

IDF (industrieel, demontabel en flexibel) bouwen is een stroming die flexibel bouwen uitdraagt. IDF beweert dat het aantal gesloopte gebouwen kan worden verminderd door ze demontabel te ontwerpen. Andere bronnen geven aan dat de toegankelijkheid en de ontkoppelbaarheid van gebouwcomponenten de sleutel zijn tot een dergelijk ontwerp.

Dit rapport beschrijft hoe de ontwikkeling van de IDF badkamer tot stand is gekomen. Het is een modulaire badkamer die ontwikkeld wordt met de IDF visie. De badkamer moet flexibiliteit bieden aan de gebruiker. Het is de bedoeling dat de gebruiker de indeling van zijn/haar badkamer eenvoudig kan aanpassen. Vooral het ontwerp van de installaties wordt uitgelicht in dit onderzoek. Het beschrijft welke beslissingen er zijn genomen, en wat de belangrijkste eisen aan de badkamer zijn.

De resultaten laten zien dat het mogelijk is om een flexibele opzet voor de installaties in de IDF badkamer te maken. De badkamer bestaat uit een frame waar wegneembare muurplaten op gemonteerd worden. De installaties worden achter de panelen geplaatst. Er zijn een aantal muurpanelen beschikbaar. Zo is er een voor het toilet, een voor de douche, enz. Elk paneel heeft zijn eigen leidingloop en bekrading. De interface tussen het muurpaneel en de basis van de IDF badkamer is gestandaardiseerd. Alleen de afvoer van het douchewater geeft significante problemen.

Een levenscyclus analyse van de IDF badkamer laat zien dat de IDF badkamer beter voor het milieu kan zijn dan een traditionele badkamer. Om dit te bereiken is er een hergebruik van 80% van de panelen nodig. Verder onderzoek zou gedaan kunnen worden naar het reduceren van het gewicht van de muurpanelen, en naar het optimaliseren van het frame.
Climate change, resource use and waste production are some of the major challenges that we face in the 21st century. The construction industry in the Netherlands is responsible for 2-3% GDP, around 30% of the CO2-emission and it causes 66% of the total waste generation. It is therefore imperative to improve the sustainability of the construction industry.

A large part (79%) of the construction industry’s waste consists of mineral waste as a result from construction and the demolition of structures. This is caused by the frequent demolition of buildings. Some buildings are demolished because their physical strength has deteriorated. Most buildings, however, are demolished because they do not satisfy the needs of their users. Typically the buildings lack spatial diversity, or they are stuck in a single function. When this is the case the building owner stands at a crossroads: to renovate the building, or to demolish it. Often demolition is less costly, because buildings are not designed for renovation/change. They are designed as static objects, built cheaply and easily. As a result those buildings have a long physical lifespan, but do not offer the flexibility to maximize their functional lifespan.

The lack of flexibility in buildings creates a mismatch between the performance of the building and the requirements of the users. When the mismatch exceeds a threshold, the building becomes obsolete and likely gets demolished. To decrease the amount of obsolete buildings, i.e. increasing their functional lifespan, the performance of buildings should continually correspond with the requirements and wishes of the users. To make this happen, buildings should be flexible and able to adapt often.
1.1 Sustainable Building

Buildings don’t last forever. Some buildings last for over a thousand years, but others are demolished within a century. What causes this discrepancy? To answer this question, it is important to understand why buildings are demolished. Structures are demolished when they get obsolete. According to Douglas (2002) this can happen for technological, structural, socio-economic, legal or functional reasons.

- **Technological obsolescence** is the result of technological improvements. A building that is technologically obsolete, is unable to implement the new technologies. When double glazing was invented (or triple glazing these days), buildings with single glazing lost some of their value. Optical fibers for data transportation have a similar story. Buildings in which a fiber network can be installed afterwards will be worth more than buildings in which it is not possible.

- **Structural obsolescence** happens naturally. Buildings get older and systems break down. A building that is structurally obsolete has deteriorated beyond repair. Installations are often the systems that will break down first.

- **Socio-economic obsolescence** is caused by a shift in the socio-economic climate. The recent trend of the so called ‘het nieuwe werken’ causes a shift in the use of buildings. Many people now work partially at home, which results in empty (obsolete) office buildings.

- **Legal obsolescence** is caused by changing regulations. It could be that, the (local) authorities decide to reserve the space for something else. Or maybe the safety regulations get more stringent. When asbestos proved to increase the risk of getting cancer, the government prohibited the use of it in new buildings. There are still difficulties in removing the asbestos from buildings.

- **Functional obsolescence** is caused by changes in user behavior. This involves lifestyles, age groups, cultures, personalities, etc. Elderly use their homes differently than adolescents. Japanese culture has different requirements to buildings than Dutch culture.

It can be concluded that buildings are not only demolished because their structure has deteriorated. They have both a physical and a functional lifespan. The physical lifespan is determined by the condition of the building. It is limited because the materials in the building slowly wear out. The functional lifespan is determined by the use of the building. User demands for the building are developing (increasing or changing) with time. When the building is not functional enough to satisfy the new demands, its function lifespan is at an end. Ideally the functional lifespan of a building should match its physical lifespan. When the physical lifespan exceeds the functional lifespan, the building materials are essentially lost. Alternatively when the functional lifespan exceeds the physical lifespan, the building will have to be replaced. It might have been designed to last longer. A well-designed building has a perfect match between functional and physical lifespan.

Structural deterioration can be addressed with regular maintenance. Once in a while a building renovation can revive the physical structure. Functional deterioration can be addressed with building adaptation. This can involve transformations inside the building, changes in the building use or the application of technologic upgrades. Building adaptation is different from maintenance. The goal of maintenance is to restore the qualities of the building. Adaptation strives to improve them (Douglas, 2002).

The problem is that the current buildings are not easily changed. They are designed with ‘outdated’ methods. Refurbishments can be costly because building systems are often intertwined with each other. A change in one system may require a change in another system, etc.; increasing the efforts and costs of the refurbishment. In some cases the building’s installations are casted within the floors. This means
that the installations are not accessible and therefore cannot be easily changed. It would, for example, be difficult to repartition the room layout, because the installations have fixed access points. If the façade of a building has a load bearing function, it limits the expansion capability of the building. Even though building refurbishment is costly, it is still preferable over demolition and rebuilding. Rebuilding a building costs between four to eight times as many resources (Power, 2008). It also is more time consuming than refurbishment. It disrupts the life of the residents for a longer period.

Buildings are not designed for the future. In most cases the physical lifespan exceeds the functional lifespan. Building design does not take (enough) future changes into account. In anticipation of future changes, the flexibility of buildings should be increased. Flexibility in this report is the ability to be easily modified. Flexibility in a building means that the building can easily be adapted to different use scenarios. The emphasis here is on the word easily. A building with more flexibility can be adapted more easily than a building with less flexibility.

This is not a revolutionary new idea. It has been known for at least 50 years. So why are there no flexible buildings? Actually there have been pilot projects that aimed to increase the flexibility. Their success was limited.

1.2 Background

Environmental awareness is an increasingly important topic. The message is clear and familiar. Wasteful use of resources and careless interaction with nature can lead to large problems in the (near) future. Consumers agree that we should conserve nature, but at what price? Is it worth it to take an extra bag to the supermarket to save one plastic bag? Are consumers really interested in buying sustainable products? The sustainable option is often more expensive. Price pressure is one of the reasons that leads to unsustainable products. Sticking to traditional implementation methods or simply the lack of knowledge can also lead to unsustainability.

Consumers need to be properly informed before they can make an environmental choice. The media play an important role in this. They seem to focus on topics that their audience can relate to, such as food waste, fuel reduction and public trash (packaging waste). Governments can also get involved. They subsidize initiatives and prohibit the use of certain materials. European law prohibited the production of incandescent light bulbs, to reduce energy consumption. Companies can also assume an informative role. For example the British supermarket chain Tesco labels some products with a carbon footprint. The carbon footprint is a measure for the amount of CO2 that has been emitted for the production, storage and transportation of the product. This is a good initiative because it allows customers to compare products on an environmental base, instead of on the traditional value for money base. This way the consumer can put a value on sustainability for himself, to determine what it is worth to them. They can consider conceding some quality for the environment. Regardless, initiatives like this are a good first step to raise peoples’ awareness of the environment.

Sustainability

A quick search reveals that sustainability is not limited to products. Everything can be sustainable these days: sustainable trade, sustainable housing, sustainable spices, sustainable business, etc. Many of these concepts aim to reduce the use of energy. This has the advantage that it immediately is cost effective. But sustainability is more than that.

Sustainability has become a way for companies to differentiate themselves from others. Bio plastics replace traditional
plastics in packaging to appear ‘green’. Certified materials ensure that the local population and environment at the source are treated fairly (for example FSC wood, Max Havelaar coffee, etc.). While these initiatives are a step in the right direction, there are also companies that misuse the image of sustainability; either unknowingly or on purpose. They mislead the customer with phrases, such as: ‘carbon neutral’, ‘green production’ or ‘biodegradable’. This is called green-washing, the disguise of bad practice with a green image. When dealing with sustainability it is important to keep the complete picture in mind. This is what makes it so difficult. Few people know exactly what sustainability is.

There are two myths regarding the preservation of the environment. The first is that the use of resources should be minimized as much as possible. It is unpleasant; not something that we want to hear. Moreover, it is not completely true. The second myth is that technology will develop so quickly that there really are no problems. It relies on the hope that in the future some technology will solve all our problems. Both stances are ignorant to the problem. Alternatives are also possible.

There are many definitions of sustainability. The definition of sustainable development by the World Commission on Environment and Development (Brundtland commission) is often used (WCED, 1987): “Sustainable development is development that ensures it meets the needs of the present without compromising the ability of future generations to meet their own needs”. To achieve a sustainable economy, Herman Daly suggests three guidelines (Daly & Bluestone, 1973):

1. The use of a resource should not exceed its natural rate of regeneration.

2. The use of a resource should not exceed the rate of finding a technological replacement for the resource. Some resources do not (or very slowly) regenerate, such as natural gas. This means that the resource reserve is depleting.

Before the resource runs out, a replacement has to be found.

3. The rate of pollution should not exceed the assimilative capacity of the environment.

These guidelines disprove that myth that sustainability is all about the reduced use of resources. On the contrary, the use of a resource use is encouraged. There is a difference between using a resource and overusing it. The use comes with the responsibility of finding replacements for the resource. This is important, because the lack of a replacement for when the resource runs out compromises the ability of future generations to meet their own needs. Resource use also comes with the responsibility to take care of the environment. The environment has boundaries with regard to the amount of pollution it can sustain. Crossing these natural boundaries can escalate environmental problems very quickly. The environmental impact of our actions should be limited.

The EU recognizes the need for sustainable development. According to its website, the current focus is the protection of endangered species and habitats and more efficient use of natural resources. The European commission has set objectives for 2020 in the environmental Europe 2020 policy. The policy aims to reduce the environmental impact on multiple levels. Not only are the direct causes addressed, but the indirect causes are also addressed, such as investment in R&D.

**Environmental Impact**

Environmental impact is the damage that is done to the natural environment. Environmental impact is a broad concept that cannot be easily measured. There are (computer) models that try to predict the impact. These models can be useful in understanding what the relation is between populations and the environment. Certain aspects of environmental impact can be measured (estimated) to give an indication, such as CO2 emissions. This is useful to
improve the models, and to set trend lines for better prediction.

The first basic model of environmental impact is the IPAT model. It is an equation that shows which factors determine the impact of a population. IPAT states that environmental impact of a population equals the product of the population size, its affluence and its technological development (Ehrlich & Holdren, 1971).

Population size and affluence will both rise in the near future. The world’s population size will rise by around 40% over the next 50 years. National income is a good approximation of the affluence factor in the equation. There is an upward trend in the average national income. This leaves technological development as the factor to balance out the other two. However, this will be difficult, because population size and affluence are rapidly increasing. It seems that a future solve-it-all technology is not so likely.

The IPAT-equation can be used to determine a rough strategy for impact reduction. As an illustration it is applied to three countries: Germany, Russia and Nigeria. In Nigeria the population is very high, which results in a (relatively) high environmental impact. It would be appropriate to apply a strategy aimed at reducing the population size, such as investing in education, social security and family planning. In Germany the population size is stable; they are highly developed. In that case a good strategy would be to promote reduced consumption. The impact of Russia is similar to that of Germany. Their lower consumption is balanced by a lower technological development. A good strategy for Russia should be focused at widely implementing technology (D. Meadows, Randers, & Meadows, 2004).

The IPAT equation is basic, but it helps understand what causes environmental impact (WCED, 1987). There are also more complicated models that offer a better prediction of future events.

**World model**

In 1972 the Club of Rome published The Limits to Growth. The book presents a world model that takes more of the world’s systems into account than the IPAT equation, such as resource depletion, food production and industrialization. The model is able to project scenarios for the future of the world. The scenarios demonstrate that population and wealth will collapse when one of the limited resources (material resources, un-eroded soil or pollution assimilative capacity) has run out. Although the model is not precise, it gives an indication of the world’s behavioral tendencies (D. H. Meadows, Meadows, Randers, & III, 1972). The book raised people’s awareness of global issues like pollution and resource scarcity.

In a later update of the book, the authors concluded that humanity has already overshot the earth’s boundaries and that it
is impossible to avoid a collapse. However, the effects of the collapse can be reduced if governments and companies start to look at the long term, instead of seeking immediate gain. Among other measures he suggests that the growth of populations and capital are particularly vicious and should be slowed down (D. Meadows et al., 2004).

**Ecological footprint**

Ecological footprint is another approach to determine the impact of a population. The impact is measured based on the consumption and pollution output of the population. Rees (1992) describes the ecological footprint of a city as the area of the earth’s surface that is required to sustain that city. The city’s primary food consumption, wood products, fuels, waste-processing capacity, etc. each correspond with several hectares of productive ecosystem. His findings indicate that the area that is required to sustain a city is at least an order of magnitude larger than the area enveloped by its boundaries (Rees, 1992).

The Global Footprint Network is a foundation that calculates the ecological footprint of various nations. Ecological footprint is expressed in the global hectare per capita (gha per capita). The bio-capacity of the earth (1.8 gha per capita) is not enough to sustain the amount of worldly consumption (2.7 gha per capita); to sustain this amount of consumption 1.5 earths are required. A longer period of overshooting the bio-capacitive boundaries may put many ecosystems at risk (Global Footprint Network, 2010). The situation in European countries is even worse. For example, to sustain the Netherlands (6.2 gha) more than three earths are needed.

**Environmental issues**

Collecting and storing environmental data is a global effort. The measurements fluctuate strongly; only long term averages can be properly interpreted. When data deviates from the predictions, it may take a long time before the cause can be determined. Maybe there is a new environmental mechanism that hasn’t been seen before. Maybe it had been disregarded in the model that makes the predictions. It is also possible that the measurement was inaccurate.

The European Environment agency recognizes four environmental themes: Climate change; Nature and biodiversity; Natural
resources and waste; Environment, health and quality of life (EEA, 2010; IPCC, 2007). Two of them are highlighted in the following sections.

Climate Change

Climate change (also known as global warming) is recognized as one of the most prominent environmental problems in the 21st century. The movie An inconvenient truth by Al Gore warns about the possible results if global warming is ignored; melting icecaps and flooded cities. Although the movie has received a lot of criticism on its scientific base, it illustrates the global nature of the problem.

There are clear signs that the climate on the earth is changing. Measurements of atmospheric concentrations of greenhouse gases (GHG) show huge increases since pre-industrial times. The increase of GHG emission is the cause of an increase in global mean temperature. Temperature measurements show an increase in global mean temperature. Increases in sea level and decreases in snow coverage serve as a further indication of a warmer climate (EEA, 2008).

The warming of the earth is caused by a process called radiative forcing. Greenhouse gases absorb and ‘reflect’ some of the infrared radiation that is radiated from the earth. The amount of heat reflected increases with the amount of GHGs in the atmosphere. CO2 is the most important greenhouse gas. It is responsible for 64% of radiative forcing. Since 1750 the atmospheric concentration of CO2 has increased by 39%. This increase is mostly caused by the combustion of fossil fuels, deforestation and change in land-use (WMO, 2011). The IPCC concluded that the increased emission of GHGs and global warming in the past few years are very likely to have been caused by human influence (EEA, 2010).

The effects of climate change are visible at a local and a global scale. Globally it can result in shifts in precipitation patterns, rising global mean sea level, the retreat of glaciers and decline in the extent of ice coverage in the Arctic sea. Locally, river runoffs are predicted to change and there is an increased flood risk for urban areas (EEA, 2008). Other consequences of changing climatic conditions include increases in global mean ocean temperatures, widespread melting of snow and ice sheets, ocean acidification, and extreme climatic events including heat waves (EEA, 2008).

To combat the dangers of flooding and peak rainfall, the Netherlands are strengthening their river dikes and coastal defenses. The EU aims to limit the global temperature to no more than 20 degrees in 2050. For this reason, the Netherlands has binding targets of 16% reduced GHG emissions and 14% of energy should come from renewable sources in 2020 compared to 2005 levels (Ministry of Infrastructure and the Environment, 2012). CO2 emissions are also addressed globally. The Kyoto Protocol is an international agreement that sets binding targets for its member countries for reducing the emission of the six main greenhouse gases. The protocol entered into force in 2005, and set emission targets for 2012. To reach the targets countries can reduce their emissions, trade emission rights or join in development projects (UNFCCC, 2008). The Netherlands signed the Kyoto Protocol in 1997, pledging to reduce the CO2 emission by 6% in 2012 compared to 2005-levels (Ministry...
The energy industries are the largest emitter of CO2 (Eurostat, 2012b). A recent study by the US Department of Energy traced the energy use in American households back to their source. Most emissions are caused by space heating/cooling. Other building installations also cause a significant amount of emission: 14% for water heating and 10% for lighting and electronics (US Department of Energy, 2012).

It is difficult to exactly determine total CO2 emission caused by the building industry, because it is spread out over multiple sectors. Building use, embedded emission in building material, construction and transport all contribute to the total CO2 emission. A study by Monahan and Powell suggests that at least 30% of the CO2 emission is caused by buildings (Monahan & Powell, 2011). Around 50% of CO2-emission by buildings in the UK can be attributed to old ‘energy inefficient’ buildings (Power, 2008).

Most of these materials are accumulated in the economy. The rest ends up as emissions or waste (EEA, 2012).

The harmful effects, created by the production of waste and the use of resources, are closely linked with economic growth. For this reason, EU policy aims to decouple economic growth from environmental degradation. The EU stimulates material reuse and recycling, as well as services (low-resource-businesses). These measures have been successful in achieving a relative decoupling. (EEA, 2010).

In the last few years, annual waste production is hovering around 5 tons per person. One third of this waste originates from the construction industry. The waste generation in the Netherlands in 2010 was more than 2 tons per person higher than the European average. The construction sector is the major contributor to this difference (66% in the Netherlands versus 33% in Europe). If it is disregarded the Dutch waste production would be well below European average. It seems that a reduction of construction waste goes a long way in reducing the total waste amount (Eurostat, 2012a).

Mineral waste from construction and demolition is the largest waste stream in Europe and the second largest in the Netherlands. This waste stream mainly consists of brick, tiles, asphalt and concrete. To reduce this waste stream, the Waste Framework Directive of the EU has set a target of 70% reuse, recycling and recovery for non-hazardous construction and demolition waste, to be met in 2020 (EEA, 2012).

**Natural resources and waste**

The extraction, the use and the disposal of materials has significant impacts on the environment. The annual use of material resources is nearly 15 tons per person.
WASTE MANAGEMENT

European waste management has traditionally been based on a waste hierarchy. The Dutch waste management plan of 2004 was based on the Lansink ladder. The ladder indicates what the preferred method is to deal with products that have reached the end of their lifecycle. It shows for example that waste recycling is preferable to waste incineration. This resulted in many improvements in the waste phase of a product. Currently, the improvements that can be achieved at the end of the lifecycle are limited. Instead, the Dutch waste management starts to focus on other phases in the lifecycle. In recent versions of the waste management plan, the lifecycle of a product does not end with a waste phase. Materials can be potentially reused, if they can be extracted from the product. For this reason, the term resource management is preferred to waste management (VROM, 2012).

Cradle to cradle (C2C) is a design movement that perfectly illustrates what resource management is. One of the principles of C2C is: waste equals food. Resources can be used, but after the use, they should be returned to their ‘metabolism’. C2C makes a distinction between a biological and a technological metabolism. Biological nutrients should return to the biological metabolism, and ‘technical nutrients’ should be reused in the technical metabolism. C2C advocates environmental effectiveness, rather than environmental efficiency: “being less bad is not the same as being good” (McDonough & Braungart, 2009).

Environmentally aware companies like to make use of the ‘triple bottom line’ tripod of: ecology, equity and economy. With proper use, this can result in a positive effect on corporate accountability. However, in practice the focus seems to be more on economic benefits, whereas the benefits of the ecology and equity are merely an afterthought. Braungart suggests the use of a ‘triple top line’ design strategy. The positive benefits that can arise within the fields of ecology and equity can lead to interesting (and profitable) ideas. Additionally Braungart argues that products should be fun. Designers should pose the question: “Is this product fun to use, and fun to throw away?” (McDonough & Braungart, 2009).

1.3 TRENDS

Building flexibility is primarily determined when the building is designed. For this reason, a proper view of the future is important when creating a flexible design.

Changes in society, climate, regulation or technology can influence the lifespan of a building. Building developers are too often concerned with easy and fast solu-
tions, instead of taking the lifecycle and the building’s future use into account (Georgiadou, Hacking, & Guthrie, 2012).

Developing realistic scenarios for the future is not so easy. One possible approach is to extrapolate recent developments and trends. This should give a decent indication of what is likely to happen in the near future. This section enumerates some trends in the financial and building market, as well as population trends and labor trends.

**FINANCIAL CRISIS**

2007 saw the first light of the credit crisis. It started with stagnation in the house market in the US. Many mortgages that were not properly audited later proved to be irresponsible. For a large part this was caused by inadequate regulation. It resulted in unsustainable levels of debt that later spread via the banking sector to other countries.

The effects of the crisis in the Netherlands are very noticeable. In 2009 the national income was declining. Purchasing power declined, and many companies were forced lay off workers. The construction industry was hit particularly hard. Stringent measures on mortgage loans made it more difficult for people to buy a new home, which ultimately resulted in the decrease of new building projects. However, the latest trends show a revival in revenue.

**BUILDING MARKET**

The financial crisis does not seem to have left a mark on the amount of buildings in the Netherlands. Even in 2009 there was a net gain of nearly 50 thousand buildings. Since 2002 more than half a million new buildings have been built. Around 15 thousand buildings are demolished every year.

In contrast to the building quantity, the building market is suffering from the crisis. The residential housing market has undergone a large decline since the start of the crisis in 2007. According to the NVM, in 2012, the yearly sales of residential properties has nearly halved from 150 thousand properties to 82 thousand. The amount of houses that is offered for sale has increased to 235 in the third quarter of 2012. Additionally, house prices have dropped significantly and the time to sale has increased (NVM, 2012a).

In 2012 there was a 14% vacancy rate within the office market. The vacancy is largely concentrated in the Randstad. Most of the vacant properties are located on formal locations (i.e. business parks), while the vacancy on urban and other locations is substantially lower. Offices on formal locations are restricted by the zoning plan, whereas offices on urban and other locations might be rezoned (NVM, 2012b). However, projections show an increased demand for office buildings until 2020, based on the growth of office jobs. Past 2020, the demand will be based on qualitative shortages of the current building stock (E. I. v. d. Bouw, 2012).

**DEMOGRAPHY**

The population in the Netherlands is growing for as long as it has been measured. It is projected that the growth continues until mid-21st century. A stagnation of population size is common with mature

![Figure 10: GDP developments in the Netherlands between 2005 and 2011 (CBS. 2012).](image)

![Figure 11: Yearly amount of constructed and demolished houses in the Netherlands (NVM., 2012a).](image)
populations. It happens when a population reaches a certain standard of living. A high population size is associated with a high environmental impact, but the composition can be just as concerning. The Dutch population is aging.

Thanks to good living conditions and healthcare, the average age of the population in the Netherlands is rising. The percentage of people over 65 has increased from 12.9% to 15.6% over the last 20 years (Garssen, 2011). The expectations show that this will rise to at least 25% in 2040 (Poelman & Van Duin, 2012). An aging population causes difficulties with the retirement system, which relies on the working population to pay for the retired population. State retirement pensions and retirement pension funds are stretched for money to cover the additional expenses, which could result in a cut back on monthly payments. The government is increasing the retirement age to cover part of the expenses; people who live longer, should also work longer (Ministerie van Sociale Zaken en Werkgelegenheid, 2013).

Due to immigration, the population will consist of around 25% foreigners. As a result, the amount of cultures represented in the Netherlands will rise. This increases the diversity of requirements to houses. There is an increased chance that the next house owner does not share a culture with previous owner. They likely have different requirements and in some cases the house will be adapted to the new situation (Schreuder & Van Rijn, 2003).

The total volume of healthcare increases by ca. 5.5% per year. This growth can be attributed to a combination of an increased amount of elderly people, but also to an increased intensity and duration of the care (CBS, 2009). To meet the growing demand, a large share of caretaking is transferred to the homes of the patients. Homecare has some advantages over hospital admission. Studies show that homecare is cheaper than hospital admission. However, a recent study by Goossens argues that those studies do not properly account for relocated costs and overestimate avoided hospital costs (Goossens, 2012). Besides cost advantages, patients may simply prefer to be treated at home. Most people would rather be treated by family and friends, than by strangers. Homes sometimes have to be slightly remodeled to be suited for homecare. Elder people have reduced mobility and therefore have different needs to their home. In the bathroom for example, they could require a raised toilet seat, support arms, a shower seat or even a patient lifter (Pressalit Care, 2007). The government supports home adaptations like this, with the law WMO.

**LABOR TRENDS**

There is a shift in the way people work. In the Netherlands this movement is called: ‘het nieuwe werken’ (Bijl, 2009). The idea is that employees can choose how, where and when they work, as long as they reach the agreed goals. This type of modern labor is aimed at increasing the organizational flexibility of the employees. By granting them responsibility they get more engaged with the company. Apart from cutting costs, this can lead to office innovations and independent workers. Modern labor is possible because of the emergence of ICT and knowledge- and communication technology. Not every job can be part of ‘het nieuwe werken’. As of now, a plumber has to fix a leak on location and cannot do so from his own home.

Many industries depend for their labor on skilled workers. The amount of plumbers, electricians, etc. is gradually declining. The economic crisis plays a role in this, as many jobs in the construction industry are lost. The chairman of UNETO-VNI, Marcel Engels, said that a shortage of skilled laborers will slow down the growth of the...
installation sector (Uneto-VNI, 2012). Students have the feeling that work in the installation sector is both heavy and dirty. In 2010, the amount of students with a technical education decreased by 26% over 2009. To motivate students for technical education, the government is spending extra money (F. Bouw, 2010).

1.4 Towards IDF building

In the past centuries the construction sector has only slowly developed. While there have been some innovations, these were often added to the existing structure. The structure itself has not been innovated. Stacking innovations are the result of a complex cooperation between the parties within the building supply chain. Each party is limited by its position in the chain and unable to innovate in other places. The result is that innovations are implemented only on a component level. On a building level the structure remains relatively unchanged. Our current buildings are an ancient heritage that is not optimally suited to our needs (Lichtenberg, 2005). An integral approach is needed with close cooperation between multiple relevant parties.

In 1999 the IFD program was created to stimulate the knowledge and application of flexibility and industrialization in construction. IFD building is short for Industrial, Flexible and Demountable building. It is a movement that encourages integral cooperation between all parties in all phases of the project. The IFD program was partly subsidized by the Dutch government. To qualify for this subsidy, a project had to meet a set of criteria to determine whether it was an IFD project or not (SenterNovem, 2007). Between 1999 and 2005 a total of 92 pilot projects were realized and evaluated (Crone, 2007). The evaluation report showed two drawbacks. Firstly, the targets of IFD proved to be ambiguous. While some projects focused on user flexibility, others focused on process flexibility or on industrial production. Integral cooperation between all disciplines, which has been the initial intention of the program, was unachieved. This also caused communicative problems between the parties in the project. Secondly, it proved to be very difficult to realize demountable buildings. Even though the goals for innovation and reduction of environmental impact through flexible design were achieved, many projects had exceeded the budget. This could be attributed to inexperience with these types of projects, but in light of the current economic crisis it is problematic (Crone, 2007).

The IDF movement started a few years after the IFD demonstration program had ended. Similar to IFD, IDF building aims at integral design and improving building performance: environmental performance, economic performance and social performance. Within the Pioneering foundation, a group of 12 companies works together with students to achieve integral design solutions. Pilot projects help this IDF group to get experience with the implementation of IDF in construction. There are momentarily two pilot projects: a modular bathroom, and a building extension module.

1.5 Problem definition

The majority of the construction industry has fixed methods of building. The building methods are incorporated throughout the entire chain, from suppliers to the users. While the end user clearly benefits from flexible buildings, the other parties in the chain may not see the advantages. Furthermore, the construction industry is heavily price-driven. Flexibility requires a higher initial investment. To change the future of building, the large construction companies need to be convinced of the advantages of flexible building. To do this it has to be tested on a small scale first. This project
focuses on the development of the IDF bathroom. It is one of the pilot projects of the IDF group.

The IDF bathroom is an initiative to create a flexible bathroom. It is developed by 4D-architects in cooperation with Winkels Techniek, Van Dijk Bouw, Plegt Vos and Raab Karcher. The bathroom is designed to provide a great amount of flexibility and reuse. The development of a flexible bathroom ties in well with the theme of increasing the sustainability of buildings as a whole. This is because it is difficult to modify a traditional bathroom. It often comes down to forcefully removing all of the tiling, which not only takes an investment of labor and time, but also creates a pile of rubble. It is a waste because most of the removed materials were perfectly fine. With proper design, those materials may have been reused. Furthermore, the process of remodeling a bathroom is very costly and lengthy. The process can be very invasive in the lives of the tenants. In some cases the access to their bathroom is denied for over two weeks.

Despite all the issues, private bathrooms are rebuilt about once in 15 years. Housing corporations use a 30 year depreciation time of their bathrooms. Everyone has a different opinion on what they like in their bathroom and what they don’t. Some people prefer a shower, while others please a bath. However, once a bathroom setup has been chosen, it cannot be easily modified. Issues with the bathroom can arise when the family composition of the users change, or when the users age.

Within nursing homes there exists a need for more rapid bathroom alterations. The patients and elderly people often have different needs of a bathroom than other people. These needs range from the installation of shower seats and supporting bars to the modification of bathroom fixtures to be wheelchair accessible. The Dutch government is even supporting the modification of homes for elderly and disabled in the WMO (Wet Maatschappelijke Ondersteuning). This law governs the local municipal authorities to financially support some changes to homes, including in the bathroom.

The main reason why a bathroom modification involves destructive behavior is that its systems display a high degree of intertwining. The installation system clearly shows this. The installations are placed inside the wall, behind the finishing layer. Although this gives the bathroom a pleasant appearance, it also makes the system very static. Because of this, small adaptations in bathroom are neglected, even though the user might have a need/wish for them.

The IDF bathroom makes it possible to make small adaptations in the bathroom, without destruction. It is a modular concept that consists of metal support frame and interchangeable wall panels. A variety of wall panels can be installed, each with a specific function. For example, there is a shower panel, a toilet panel, a sink panel, etc. The wall panels can be easily removed, and replaced. This allows for a very flexible system in which the user is free to choose a setup. It is possible to quickly change the bathroom to a setup where the whole wall is covered with sinks, if the user so desires. But other, more likely, options are also possible. The overall structure for the IDF bathroom has already been completed, but some of the details have yet to be filled in. How the installations will be placed in the IDF bathroom is one of the major missing details. This project focuses on the design of the installations.

**PROJECT GOAL**

The goal of the project is to design an innovative, flexible and modular installation concept for the IDF bathroom, by developing and applying IDF design criteria.

**RESEARCH QUESTIONS**

Main research question: How can IDF be applied to the design of a flexible
and demountable bathroom installation system?

1. How does IDF building solve the problems in the construction industry?

2. How does IDF building translate into design criteria?

3. Which flexibility is expected of the IDF bathroom?

4. How can installations be designed modularly?

5. Does the application of IDF to a bathroom increase its flexibility?

6. Does the application of IDF to a bathroom increase its sustainability?

**PROJECT SCOPE**

This project involves the installations in the IDF bathroom. Flexible integration of the water installation, the wastewater installation, the ventilation installation, the electric installation, the heating installation and a data installation are considered for this project.

Because the focus is on the installations, some other objects are outside of the scope of this project. The engineering of the support frame for the IDF bathroom is not taken into account. Improvement for the wall panels are also not taken into account.

**METHODOLOGY**

The project consists of five phases.

A literature study results in an understanding of the problems in the conventional construction industry. It shows how it contributes to environmental and social issues, and what the cause is of these problems. Projections of the future are explored in this phase.

The second phase is based around the development of IDF design criteria. This section elaborates on what IDF is, and how it aims to solve the problems. A model is proposed that explains how the criteria relate to each other. The model is based on literature.

In the third phase, the integration of the installations is designed, based on the IDF-criteria from the previous phase. Also general design criteria such as user and legal requirements are considered. First a basic structure is defined. Next, the interfaces are looked at in more detail. When the design is finished, it is built into a prototype, to determine if the design works in practice. An LCA of the design determines in what areas it can be improved, and how it compares to a traditional bathroom.

In the evaluation phase the results are compared with the project goals. The IDF criteria are used to determine whether the design is successful.

The last phase discusses if the results are preferable or not. It indicates what the problem areas of the IDF bathroom are, and gives suggestions for improvement. This section suggests what needs to be done to improve the model, and what interesting possibilities are for future research.

**PROJECT RESULTS**

The project results in IDF design criteria that can be used to evaluate whether building systems are (IDF) sustainable. The criteria are based on literature.

The second result is the design of an installation concept. The design is implemented in a prototype, and evaluated with the IDF design criteria.

**PROJECT RELEVANCE**

Flexible and demountable buildings have been tried before. The IFD program may have been the most noteworthy (refer to section 1.4). In that project it has been showed that fully demountable buildings are very difficult to be designed. A building consists of many components. It is wise to start on a small scale first. The IDF bathroom is one of these small projects. It is
used to show that it is indeed possible to make a demountable design.

The development of IDF criteria is useful to other designers who are dealing with similar problems. One of the complaints of past projects is, that there is confusion about what it flexibility means in a boiling. This project can provide a test case to show what flexibility in a bathroom means. That can then be extrapolated to a building scale.

The IDF bathroom can help to reduce some of the social problems that are projected for the future. More about the projections is described in the trends section of this chapter (1.3).

The population in the Netherlands is aging. It is projected that the amount of people over 65 years of age rises to over 25% of the total population. This increase is accompanied by an increase in care costs. A shift towards homecare could be the solution, but only if the home is able to change to a care situation. The difference between a care home and a non-care home can be specifically seen in the bathroom.

There is a large amount of vacant office buildings. These buildings have to be put to use, to avoid their demolition. It is possible to transform the office space to rental apartments. However, this is often difficult, because of the layout of the installations in the office building. Office space needs far less bathrooms per square meter, for example. The creation of a modular bathroom makes it possible to reduce the vacant building stock.

During an economic crisis, the amount of houses that are available for sale increase. It is associated with an increased sales time. Users sell their house because the house doesn’t suit their needs any more. The users have ‘outgrown’ their house. If the house would be able to grow with the user, the need for relocation would be reduced.
IDF stands for Individual, Sustainable and Flexible. The goal of IDF building is to design sustainable buildings that can be adapted to the needs of the individual. IDF does this by introducing flexibility in buildings. The focus is mostly on the disassembly of buildings into building components, with the realization that the building components should match the wishes of the user. IDF regards sustainability over the entire lifecycle of the building and considers energy efficiency, social acceptation, building lifecycles and reuse by deconstruction (Pioneering, 2013).
2.1 Centralizing the User

Everyone has different needs of their home. Culture, religion, age and personal taste can cause people to like or dislike a certain house. Buildings are home to many individuals during their lifetime. It is unavoidable that the building sometimes doesn’t match very well with the needs of the tenant. In those cases, it the value of the building can be increased. But to understand how the building needs to be changed, it is important to understand the user. Buildings are often designed with the initial user in mind, but this is an outdated concept, because the building lives longer than the user.

Design for individuals is already common practice in other industries. For example in product design it is unthinkable to separate the user from the product. The construction industry is lagging behind, but the users can no longer be ignored.

1. Performance phase: New products often have functional problems. In the first phase the product’s primary functionality is improved.
2. Optimization phase: When the product’s primary functionality is sufficient, other ‘secondary’ product properties are improved, like reliability, ergonomics and safety.
3. Itemization phase: In the third step the focus is on convenience. Ergonomics are also improved.
4. Segmentation phase: Specific market segments are targeted. Products can be equipped with additional functionalities or emotional benefits, to distinguish them from competitors’.
5. Individualization phase: In this phase the products are created for individuals. The production process has customization options to create unique products.
6. Awareness phase: The last step is to increase the social and environmental benefits of the product. The producing company communicates their company ethics in promotion campaigns.

Comparison can be made with product design. Product development is much faster than developments in construction, because product innovations can be more easily made across a large section of the supply chain. Eger suggests that product development goes through six distinct stages (Eger, 2007). He calls it Evolutionary Product Development (EPD). EPD is a descriptive model but it could be used to predict how the product might develop. The first two stages are related to the product itself. In those stages mainly the functionality of the product is improved. The later stages revolve more and more around the user. Products become easier to use and their ergonomics increase. Then the product is targeted to specific user groups (segmentation), and even later to individuals. The final stage in the EPD model is an awareness phase. Here the product increases its sustainability and ethics.

Buildings can be regarded as products, although a bit larger. Comparing the development of houses with the EPD model, one can conclude that the development is between the individualization and the awareness stage. There is market segmentation in houses: for starters, for large families, for elderly, etc. However, besides the people who are able to build their own house, the individualization in buildings is lacking. Of course, this partly has to do with the large lifespan of the building. There are some opportunities for a construction company to involve users. In many new building projects the initial residents can influence the design of the building. Sometimes they can determine the layout of the inner floor plan, or they can determine where they want the living room, bathroom or kitchen. Nearly all of the projects in the IFD program offered flexibility like this. However, it only increases the value of the building for those initial users. There is little to no individual-
ization possible for new residents in older homes.

### 2.2 Sustainability

The awareness stage in the EPD model seems to break through in house development. Energy efficiency is a particularly popular topic (Eger, 2009), which corresponds with the IDF goal of sustainability. Inefficiency is often caused by user behavior, or outdated building installations. Regarding energy inefficiency it is key to inform the user of how much he is using. A report by the Environmental Change Institute shows that direct feedback of energy performance compared to other homes could save up to 18% of electricity savings and 9% of gas savings (Darby, 2006). A study among 137 Dutch households shows that a web based tool could lead to 8.7% energy conservation (Benders, Kok, Moll, Wiersma, & Noorman, 2006). Although these are interesting ideas, IDF mostly focuses on the material side of sustainability.

### 2.3 Flexibility

The previous chapter explained why flexibility in building is needed. It didn’t reveal how it can be done. On the contrary, the IFD program showed that it is not so easy to incorporate flexibility into buildings. How do you know if a building is flexible, or not? There have been a few attempts to design a method, which determines the flexibility of a building.

In 1996, Geraedts proposed the Flexis method, to assess the flexibility of installations and their components (Geraedts, 1996). The method distinguishes four key performance indicators of user flexibility: partitionability, adaptability, extendibility and multi-functionality. Each indicator is composed of a few sub-indicators. For example, the sub-indicators of extendibility are local capacity, central capacity, dimensions of distribution network and location. To get a final score in this method, each of the sub-indicators has to be rated on a 1-5 scale. Geraedts also proposes a set of weighting factors to get a better score.

Other sources agree with the key indicators of Geraedts. After 6 years of study Brand concluded successful buildings often have large undefined spaces that are suitable for many purposes (Brand, 1994). A large room size makes it easier for users to adapt the room to their needs. Large undefined spaces are multi-functional. Reports about the IFD program also agree with the need to extend buildings (SenterNovem, 2007), and the need to reconfigure the layout (Crone, 2007).

Durmisevic introduces ‘transformation capacity’, as a measure for the flexibility of a building (Durmisevic, 2010). A high transformation capacity means that a building is flexible, and as a result it is less likely to be demolished. She proposes an extensive indicator method to determine the transformation capacity of a building. The method uses a mix of high and low level indicators. The high level indicators assess dependencies in the building, such as: are there components with multiple functions? The low level indicators assess physical components, such as: can components be easily removed? do they overlap each other?

The notion of high level and low level indicators of flexibility is interesting. It suggests that flexibility has to be considered both in concept design and in design of details. This project therefore distinguishes two types of flexibility that correspond with high and low level flexibility: flexibility on a system level, and flexibility on a component level.
System level flexibility concerns changes in the function that the system is supposed to provide. For example if a home owner decides to install a bath in addition to their shower. The function changes from ´supply water to the shower´, to ´supply water for both the shower and the bath´. If the water pipes can be easily extended to also provide the bath, the system has a higher degree of system level flexibility. This type of flexibility is responsible for building repartitioning, expansion and multi-functionality. The next paragraphs give some examples of flexibility.

Partitionability involves partitions and reconfiguration of spaces. For example a space can be partitioned into multiple smaller spaces. This requires the placement of a few interior walls. But where are the walls attached to the building? Can the floor heating be separated, or do all of the rooms have to be set to a single temperature. These are questions that the building designer has to take into account. Modularity is the key when dealing with partitions. A perfect modular system can be partitioned at every location possible. In practice it is a good idea to make use of a standard grid.

Adaptability involves changes to components to enhance their performance, without adding new components. When someone gets older, their preferred toilet seat height may change. A toilet that can alter the height of the seat is very adaptable. Adaptability can deal with changes in the use of the components. The change can involve user preferences, room use, external climate, time of day/year, etc. Adaptability is also present in software. A building automation system has a user interface where settings can be changed. It is common that the light in a building automatically turns of. Being able to manually adjust this time is a form of adaptability. An adaptable system can reduce the amount of components that is required.

Extendibility deals with future additions to the systems. On a building level extendibility might mean an increase to the building size. An extra floor can be put on top of the building, or the façade of the building might be extended outwards. On a component level this involves additional components, or upgrades to components. The addition of an optic cable network is an example of component level extendibility. The solution to extendibility is over-dimensioning of system properties. It is possible to reserve extra space for future upgrades, or to over-dimension the water pipe diameter in case of a future branch. There should be sufficient locations for expansions to the system. It can be useful to design a water pipe with ample T-junctions. In that case a branch can easily be added later.

Multi-functionality involves system or components that can be used for multiple purposes. Even if a component can be easily replaced, it is beneficial if it does not need to be replaced. For example, plastic water pipes are suitable for the transport of hot water, but only for a short time. Because this pipe is not multifunctional, it cannot be changed to a hot water circulation line. Some support brackets are able to support many different types of installations, or even other types of equipment. This makes them multi-functional as well.
COMPONENT LEVEL FLEXIBILITY

Component level flexibility does not change the main function of the system. The same home owner from the previous example, after realizing a bath would be expensive, might settle for a shower upgrade. In this case, the system’s function: ´supply water to the shower´, does not change. The upgrade involves the replacement of a component. Component level flexibility deals with component replacements, maintenance and upgrades.

The distinction between the two types of flexibility can be relevant for the improvement of a design. If it proves to be difficult to access a component, it is likely the easiest to fix the problem on a component level (locally), rather than changing the layout of the system. Alternatively, if there are problems with the connection of an additional component, it is likely because the system level flexibility was not designed well enough.

DISASSEMBLY

Design for disassembly (DfD) was originally developed for maintenance purposes. DfD is to design for easy disassembly of multi material designs (Thormark, 2001). With an environmental viewpoint, it can also be used as an end-of-life option. The disassembled parts can be reused, and do not have to be disposed.

A guide by the SEDA (the Scottish Ecological Design Assembly) gives the following advantages of DfD related to buildings (Morgan & Stevenson, 2005): it minimizes construction waste, aids local economy, reduces transport if done regionally, reduces CO2 emissions by avoiding the use of new materials and it reduces the demand on natural resources. All these advantages are created by the reuse of components that would have otherwise been demolished. If the building components can be further disassembled into materials, recycling is also an option.

During the IFD test period, it proved difficult to construct a building that could be fully deconstructed. Whether or not a system can be taken apart is determined by how its components connect to each other. The amount of connectors that is used (Güngör, 2006; Mital, Desai, Subramanian, & Mital, 2008), as well as the type of connector are relevant. Chemical connectors are best to be avoided (Crone, 2007; Mital et al., 2008; SenterNovem, 2007). They can usually not be disassembled without force or solvent. It would be difficult to replace a light bulb if the lampshade would have to be glued to the roof. Welding and soldering are other chemical connections that are often used.

ACCESSIBILITY

Most sources agree that accessibility of components is one of the most important factors for flexible design (Crone, 2007; Durmisevic, 2010; Luttropp & Lagerstedt, 2006; Mital et al., 2008; Morgan & Steven-
Component accessibility is important to be able to make changes to them.

The access to components can be restricted by other components in the system. Finishing systems in particular make it difficult to access the components behind it (Mital et al., 2008; Morgan & Stevenson, 2005). In the bathroom, it is common that water pipes are recessed in the wall. The wall is then finished with a layer of tiles. This surface makes it impossible to easily access the pipes.

Accessibility of installations can be limited by the medium inside. When servicing any electric wire, it is wise to shut off the power first. The power in this case limits the accessibility to the wires. Similarly, when doing maintenance on the siphon of the sink, the water valve should be closed. The water pressure limits the accessibility of the system. For this reason an accessible system needs to have a valve (Crone, 2007) and in some cases a drainage point (Mital et al., 2008).

Component dependency

Brand developed a hierarchical system for buildings. He distinguishes six layers (Shearing layers): Site, Structure, Skin, Services, Space plan and Stuff (Brand, 1994). Building systems can be classified according to their lifespan. He developed the layers to indicate that not every system has the same lifespan. To create a flexible system, the components that have to be replaced more often, should be placed in lower tiers. Durmisevic labels this as component lifecycle coordination (Durmisevic, 2010).

The idea behind component lifecycle coordination is that there is a relation between the lifespan of the component, and its location. The location depends on the lifecycle. There are many (other) dependencies in a system. Every component is placed in an environment. The components is attached to a support structure, or may be attached to neighboring components. In some cases it receives wireless data from an antenna in elsewhere in the room. Or it is used as a link between two other components. All these interactions create dependencies. When a dependency is made, it becomes unlikely that a component can be reused. The goal to flexibility would be to uncouple harmful dependencies.

There can be a dependency between the physical properties of a component and its environment. The beams that support the first floor in an apartment building have to carry more weight than the beams that support the top floor. It is possible to optimize the size of the beams. In that case the top floor beams could be made smaller. However, by doing this, it becomes impossible to make an expansion on top of the building (SenterNovem, 2007). In this case the support beams have become dependent on their location within the building.
The designer has to consider if a building expansion is a realistic scenario to determine if it is worth the extra material. It is also possible that a component depends on the climate in its environment (Morgan & Stevenson, 2005). This could be considered for long lasting products, such as buildings. Note that this type of dependency has always been an active decision of the designer (or an oversight).

Another type of dependency is the one between components. These dependencies can be caused by structural features of the components. A sink is suspended on two threaded rods. The distance between the rods corresponds with the distance between the holes in the sink. With other words, there is a dependency between the rods and the sink. A dependency like this can be problematic. What if the sink breaks? It then has to be replaced with a sink that has holes at the same distance. This is where standardization comes in.

The dependency between the components is broken, by introducing a standardized interface (Crone, 2007; Mital et al., 2008; SenterNovem, 2007).

Standardization is a way to deal with some dependencies. Standardized interfaces (Crone, 2007; Durmisevic, 2010; Morgan & Stevenson, 2005), standardized components (Mital et al., 2008; SenterNovem, 2007) and standardized connectors (Mital et al., 2008) help to create exchangeability between components. A standardized grid can help to reduce the dependency of components and their location (Crone, 2007; SenterNovem, 2007). The modularity of LEGO blocks is a good example of this. They can be placed to create almost any desired structure. Standardization has the additional benefit of prefabrication. This reduces the onsite assembly time.

**HIGH LEVEL DEPENDENCIES**

When dependencies are introduced in high level systems, they restrict flexibility greatly. When a façade dually serves as a load bearing wall, the building cannot be easily extended. In that case the load bearing system depends on the location of the outer wall.

These dependencies should be avoided at the start of the design. It can be helpful to map and reserve primary building functions, such as the load bearing to specific components (Durmisevic, 2010). Those components should then not be used for other purposes. This helps to avoid accidental dependencies. In case of the load bearing, a base support element can be assigned, to which all the other systems are attached (Durmisevic, 2010; SenterNovem, 2007).

As a practical guideline, it is useful to determine on beforehand which flexibility is required, rather than trying to adapt a building later. (Crone, 2007; Morgan & Stevenson, 2005; SenterNovem, 2007).

### 2.4 Industrial Building

Flexibility is achieved by a high degree of modularity and standardization. It helps when components can be used in multiple functions. Industrialized production is required to get the maximum benefits.

An industrialized process is characterized by centralization of production, mass-production, product standardization, specialization, good organization and process integration (Chew, 2005). Industrial building (or prefab building) involves the shift from onsite production to factory production. Offsite production has many advantages.

First and foremost, it drastically reduces the onsite assembly time. This reduces the amount of labor costs. The employees are protected from environmental influences, and the working conditions are generally more ergonomic. In addition to this, the amount of skilled workers is reduced. A study of seven construction projects in Sweden shows that around 45% of defects costs originate on site. Most of these costs can be attributed to a lack of worker moti-
viation (Josephson & Hammarlund, 1999). Industrialized production reduces failure costs and increases product quality.

Production equipment can be used most effectively if the output is standardized. The machines and the training of the workers can be adapted to the standardized output. With modern production techniques, even a standardized product can allow for a lot of customization and individual variation. Homogenous appearance of building should be no concern if the building components are designed well enough.

Factory production means that most of the on-site flexibility is gone. The details of interfaces and connections need to receive special care. According to the SEV evaluation report is that measurements and tolerances should be managed better (Crone, 2007). Building information modeling (BIM) can help with the management of building design. It is a software model, that increase the overview of the construction project and helps with the communication between construction partners.

The nature of the construction industry makes it difficult to fully shift to industrialized production. The environment in which the building will be built, the designers and the end-users all impose requirements on the building, which makes it difficult to standardize. Buildings have a long service time, compared to most goods, which further complicates things.

### 2.5 LCA

Lifecycle assessment (LCA) is a method that maps the phases in the lifecycle (LC) of a product. It is the most accurate numerical way available to prove that product A is better than product B. It can also help define problem areas in the product. To determine the environmental impact of a product, the LCA can be supplemented with an impact assessment method. This makes it possible to compare products to each other on an environmental basis. An LCA should be made for every product that claims to be sustainable.

Making a proper LCA is a lengthy process. It cannot be rushed. It starts with a description of the product LC. The LC typically consists of an assembly phase, a use phase and a waste phase. Additional phases can be added if required. Next, the processes and materials that are used during the phases of the LC are determined. Each process/material corresponds with an emission output. The emissions are summed up and normalized into a single unit. Finally an indicator score is determined from the normalized emissions. This involves the application of weighting factors, which makes it highly subjective. The ReCiPe-method is an example of an impact assessment method from 2008 (Goedkoop et al., 2009).

An LCA requires an abundance of assumptions. Based on the assumptions the outcome of the LCA can differ. A popular example is the question whether it is better for the environment to use single use plastic coffee cups or reusable earthenware mugs. A TNO study shows that the results of an LCA can vary, with varying assumptions: how often is the mug cleaned? Has the transport of the cups been taken into account?) (Ligthart & Ansems, 2007).

Lifecycle assessment of a product is time consuming. When the product is as large as a building, it becomes very time consuming. The sustainability of buildings is often determined with other tools. Among others: Breeam (Bre Global Ltd, 2011), LEED (US Green Building Council, 2012) and the Dutch GPR-gebouw (“GPR Gebouw,”). These tools are basically a checklist. Points can be scored for each requirement on the checklist that is measured up to. More points mean a higher sustainability. Methods like this are usually tied to certification. Alternatively they can be used as a quick-scan. One common complaint of this is that contractors are unlikely to apply measures that are not on the checklist, and that it
slows down technologic development. Also it is difficult to maintain a certified building, as the requirements on the checklist become more strict over time.

**Lifecyle improvements**

Environmental benefits can be gained in all of the phases in a product lifecycle. IDF mostly focuses on the gains in the, what would have been called the waste phase. Designing components in such a way that they never enter the waste phase. There can also improvements be made in other phases.

Many sources mention the environmental benefits of local sourcing and prefabrication (Luttropp & Lagerstedt, 2006). The reduced transport costs can add up to a sizeable saving. This also applies to building renovations. If the renovation can be done without additional material, the impact from transport is reduced (Luttropp & Lagerstedt, 2006; Morgan & Stevenson, 2005).

The use phase of a product often has one of the largest impacts. This is particularly the case for electrical devices. Maintenance also plays a big role in this. To ensure that a product can be maintained, it needs to be accessible (Crone, 2007; Durmisevic, 2010; Guy & Ciarimboli, 2007; Luttropp & Lagerstedt, 2006; Mital et al., 2008; Morgan & Stevenson, 2005; SenterNovem, 2007). This can be achieved by implementing detachable covers (Crone, 2007; Mital et al., 2008) and by the addition of valves (Crone, 2007; Mital et al., 2008).

When a product finally enters the waste phase, hopefully after a good many lifecycles, there still are a few options. Preferably, the product gets recycled. This is only possible if the product consists of easily detachable components that consist of a single material. Material blends cannot always be recycled properly (Luttropp & Lagerstedt, 2006; Morgan & Stevenson, 2005). C2C, brands these materials as ‘Monstrous hybrids’ (McDonough & Braungart, 2009).

### 2.6 Model

The previous sections mentioned some criteria that are suggested by literature. It needs to be determined whether these criteria are suitable as IDF design criteria for the design of flexible installations. For this purpose a model has been developed that links the criteria to the problems. The table below gives a full list of criteria that are considered in the model, together with the sources that mention the criteria.

The model consists of two sections. The upper section (gray nodes) contains the problem side of the model. It is built on a root-cause-analysis. A root-cause-analysis continually asks the question: ‘What is the cause of this?’ By continually answering this question, a difficult problem can be divided into smaller manageable problems. The top node has the main problem. IDF has multiple goals, but for the purpose of reducing environmental impact the main problem is: ‘the total amount of construction waste is too high’. What is the cause of this? Two reasons, too many buildings are demolished, and the amount of waste per building is too high. Etc. The analysis implements the building obsolescence theory of Douglas (2002). Note that one node (bottom right) in the problem side is not connected to the rest of the problems. This node has later been added (refer to the last paragraph of this section).

The rest of the model is the solution side (white nodes). The nodes contain the criteria that were mentioned in theory. The criteria have been grouped, to make them more easily readable. The right side consists of five groups. The top four groups are related to the Lansink ladder (prevention, reuse, recycle and disposal). They each have a corresponding potential node. Some criteria were directly related to increasing
one of those potentials, and have therefore been placed into the relevant group. For example, the node ‘homogenous component material’ corresponds with the advice to not blend multiple materials into one, as mentioned by Morgan and Stevenson (2005). This advice influences the potential to recycle the component, so it is grouped in the recycling group.

The waste prevention potential has been split up into two (or actually three) sub-nodes: flexibility potential and maintenance potential (and upgrade potential). These correspond with the system level flexibility group and component level flexibility group as described in a previous section of this chapter. The arrows indicate a further specification of the three potential nodes. The flexibility potential can be increased by the implementation of the four types of flexibility as described by Geraedts (1996). The maintenance and upgrade potential can be improved by the implementation of demountability and accessibility. In a similar way the left most two blocks (future and dependencies) are the solution to the flexibility types group.

The final step in the model involves the connection between the problems in the model with the solutions. The idea is that a solution that cannot be linked to a problem is not part of IDF. That does not mean that it should be ignored, but it means that it should not be the main focus of flexible installation design. The model contains five links between the problems and the solutions. The fifth link is added to the model, because it connects to a prefabrication node (in the yellow energy group). Prefabrication is one of the focal points of IDF, so it has been associated to a problem node ‘building use produces too much waste’. This node involves all the waste that is not cause by end of the life scenario’s.

2.7 **CONCLUSION**

Based on the model one can conclude that IDF design is effective in solving the lack of component replacement, functional changes, upgrades and component reuses. There are four things to consider during the design of an IDF installation concept.

There should be a good vision of future bathroom use. Flexibility can only be properly considered when you know who and what to design for.

Harmful dependencies between systems in the bathroom should be removed. For this reason it is advisable to start off with a structural design before the design of the interfaces between the installation. The structure contains unpolished solutions to questions like: ‘Where can the installation be expanded?’ and ‘What happens if an installation is removed?’.

Installations should be able to be dismantled. This can be done by a careful choice of connectors and suspension brackets.

Installations should be accessible. To make any changes in the bathroom it is important that there is access to the installations. This means that the components should not be obscured by other components, and that there is a clear path to reach them.
<table>
<thead>
<tr>
<th>Criterium</th>
<th>Accessibility</th>
<th>Demountability</th>
<th>Flexibility</th>
<th>Future</th>
<th>Dependency removal</th>
<th>Energy</th>
</tr>
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<td>Accessible installations</td>
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<td>Deconstruction plan</td>
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<td>Extension potential</td>
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<td>Ample connection points</td>
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<td>Define grid</td>
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<td>On site component readjustment</td>
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<td>Future vision</td>
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<td>Future use</td>
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<td>Future layouts</td>
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<td>Future environment</td>
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<td>Dependency component - climate</td>
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<td>Dependency component - location</td>
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<td></td>
<td>Dependency system - system</td>
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<td></td>
<td>Dependency component - component</td>
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<td>Standardize component interfaces</td>
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<td>Standardize components</td>
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<td>Cluster components</td>
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<td>Minimize transport</td>
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<td>Use natural energy</td>
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<td></td>
<td>On site assembly reduction</td>
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<td>Prefabricate components</td>
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<td></td>
<td>Cluster materials</td>
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</tbody>
</table>

Figure 16: Table of recommended solutions by source.

An ‘x’in the table means that the solutions on the row is mentioned by the source on the column.
<table>
<thead>
<tr>
<th></th>
<th>Reuse</th>
<th>Recycling</th>
<th>Disposal</th>
<th>Prevention</th>
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<tr>
<td></td>
<td>Reuse potential</td>
<td>Homogenous component material</td>
<td>Cluster harmful materials</td>
<td>Upgrade potential</td>
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<td></td>
<td>Durable connectors</td>
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<td>Return materials to initial state</td>
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<tr>
<td></td>
<td>Durable materials</td>
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<td>Maintenance potential</td>
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</tbody>
</table>

- X indicates the feature is present.
- Blank space indicates the feature is not present.

Sustainable building components
Figure 17: Theoretical model of IDF design.
3 Bathroom Requirements

The previous chapter explains the principles of IDF, and what factors must be taken into account. This rest of the report focuses on the application of the IDF principles. Fortunately, IDF building doesn’t have to be immediately tried on a whole building. It is an idea to try and apply it first to a small section of the building. The IDF bathroom project has been chosen as the pilot project.

This and the next chapter present a possible design for the installations of the IDF bathroom. It also explains how the IDF bathroom is flexible. This chapter works towards design criteria for the bathroom.
3.1 IDF BATHROOM

A bathroom is a personal space. Everyone has a different opinion on what they like in their bathroom and what they don’t. Some people prefer a shower, while others would rather have a bath. However, once a bathroom setup has been chosen and installed, it is difficult to make any kind of significant modification. Issues with the bathroom can for example arise when the family composition of the users change, or when the users age.

Private bathrooms are rebuilt at a rate of around 15 years. Housing corporations use a depreciation time of 30 year for their bathrooms. Within nursing homes there exists a need for more rapid bathroom alterations. The patients and elderly people often have different needs of a bathroom than other people. These needs range from the installation of shower seats and supporting bars to the modification of bathroom fixtures to be wheelchair accessible. The Dutch government is even supporting the modification of homes for elderly and disabled in the WMO (Wet Maatschappelijke Ondersteuning). This law governs the local municipal authorities to financially support some changes to homes, including in the bathroom.

The modification of a bathroom is not an easy task. It often comes down to forcefully removing all of the tiling, which not only takes an investment of labor and time, but also creates a pile of construction waste. It is a waste because most of the removed materials were perfectly fine. With proper design, those materials could likely have been reused. Furthermore, the process of remodeling a bathroom is costly and lengthy. The process can be very invasive in the lives of the tenants. In some cases the access to their bathroom is denied for over two weeks.

The main reason why a bathroom modification involves destructive behavior is that its systems are highly intertwined; in particular the installations clearly show this. They are placed inside the wall. A finishing layer blocks the access to the installations. The layer may give the bathroom a pleasant appearance, but it also makes the system very static. The user does not make small changes in the bathroom because of this.

**UNIQUE SELLING POINTS**

From the introduction it becomes clear that there is a need to be able to make changes in the bathroom, but that it is not easily possible to do so. The IDF bathroom is specifically designed to remove this impossibility. It has been designed with the IDF ideas in mind: prefabricated, modular and flexible leading to individualization and sustainability.

The modular setup of the IDF bathroom gives it three major advantages over a traditional bathroom. The first is the flexibility that the modular setup gives. Unlike a traditional bathroom, the IDF bathroom can be altered easily. Secondly, the onsite installation time of the IDF bathroom is lower. The pipes do not need to be placed in the wall, which saves time. Cladding the wall with tiles is no longer needed with the IDF bathroom. The wall panels of the IDF bathroom provide a finishing layer, whereas the wall in a traditional bathroom is often covered with tiles that are manually placed. The third advantage is in the last stage of the bathroom. The IDF bathroom can be fully disassembled, and its components can be reused or recycled.

Other bathroom developers have also noticed the advantages of a modular prefabricated system. A few companies have developed a bathroom unit that can be inserted via the façade (International Project Design B.V., 2013; Logus Prefab, 2013; Portisa, 2013). However, because of how it is installed, these are only suited for new buildings or large renovation projects. The IDF bathroom has the advantage over these concepts that its components can be brought into the building via the door. This
makes the IDF bathroom suitable for small renovation projects.

Other developers divided their bathroom into large modular sections that are just small enough to pass through doorways (S-Pod, 2013), or in some cases it is divided in wall panels (Faay Prefab Products, 2013). Yet other systems rely on modular wall systems to implement the bathroom (Geberit, 2013). There are numerous developers of modular wall systems. Most of these systems are aimed at a fast installation time. However, they do not offer the same flexibility as the IDF bathroom. In other cases they cannot be easily disassembled.

In conclusion, the strengths of the IDF bathroom are its flexibility, reusability and a low onsite installation time. The design of the installations should be evaluated according to these strengths.

**Ideal final result**

The IDF bathroom is in continuous development. To do this effectively there must be an end goal. What should the final product look like?

Ideally home owners should be able to place and remove the wall panels of the IDF bathroom by themselves. This reduces the job of trained mechanic to the initial preparation of the bathroom. The installation itself would be quick and painless. The installations would be able to plug in themselves while the panel placed. The wall panels would be available at every DIY market. There would be many variations of the wall panels available. Not only panels with different functions, but also with different types of cladding and colors. A panel made of composite materials can be made in any shape, even with cabinets inside.

**Project state**

The project started with a design for the physical structure of the IDF bathroom. There is a design for a metal support structure. The structure can be fixed to the wall with chemical anchors. It has two rails that are used as a suspension point for the wall panels. In the current design, the wall panels consist of a large sheet of bio-composite material. Two sections (one at the top and one at the bottom) of the panel can be separately detached. This ensures that the installations within the wall are accessible.

A prototype has been created to test the structural design and the aesthetics. It was showcased in various exhibitions and symposia. There were some issues during the installation. The design offered readjustment possibilities to make sure that the wall panel was perfectly horizontal. It
proved to be difficult to readjust the panels, because the adjustments were inaccessible. Photos show a mechanic who reaches over a panel to adjust it. This would not be possible in a bathroom because of the roof. The design proposed ball snappers to attach the detachable sections of the wall panel. A rubber strip made sure that the panels were waterproof. The pressure of the rubber strip made it difficult to click the panel in the ball snapper.

The evaluation of the prototype resulted in two subprojects. The first was related to the waterproofing of the wall panels. Students from the Saxxion University are working to create a solution for the waterproofing. This report focuses on the second subproject, the placement of the installations.

3.2 **Bathroom requirements**

As a guide to the design process, a list of design requirements has been developed. The full list can be found in the appendix. The requirements are based on the users, on the use of the bathroom, on the technical properties of installations and on regulations.

The primary function of a bathroom is to provide users a means for personal hygiene. This includes a provision to shower/bath, a provision to wash up and a provision for going to the toilet. Other functions of the bathroom support the main function. These allow comfortable use of the bathroom. For example, the user requires sufficient lighting and sufficient ventilation for clean air.

In addition to the primary bathroom functions, users may have other wishes. They may want to use the bathroom to style their hair or to put on makeup. This requires specific (additional) lighting that can be
enabled at will and is more intense than the ambient lighting. Other users might want a place in the bathroom to use or recharge their electrical equipment: in particular electric toothbrushes and shavers.

**TARGET GROUP**

Everyone is a bathroom user. That is both a blessing and a curse. The market is very large, but the needs and preferences may vary, making it difficult to define a single type of bathroom user. Generic demands of a bathroom, such as the ability to wash up and to go to the toilet, can be determined without much trouble. Other requirements come from specific target groups. Originally the IDF bathroom had been specifically designed for patients and caretakers in a care home. There is a scenario where two single person apartments would be merged in a single two person apartment. This change is accompanied by the transformation of a bathroom into a kitchen. The IDF bathroom should be able to allow this transformation in a comfortable way.

Patients in a care home often are not fully mobile. Similarly to elderly at home. They may require the use of walking aids or move in a wheelchair. A circle of 1.5 meter radius is required to turn around in a wheelchair. Additionally, the doors need to be wide enough. Any unevenness in the floor, such as doorsteps or an object like a shower tray can be a great hindrance. A large amount of elderly suffers from impaired vision. To prevent the risk of tripping over objects in the bathroom, it is important that there is sufficient light. A light switch in the bathroom (dark at night) might be difficult to reach. Handles and seats can be installed to support the patients. For example a seat can be installed in the shower if patients are not able to stand for a longer period. A supporting bar can be installed next to the toilet to help the user stand up. The walls need to be strong enough to be able to carry those (future) provisions. A thermostatic faucet can be installed to prevent burns. It then is impossible to maximally open the hot water supply.

The role of the caretaker differs from patient to patient. ArjoHuntleigh differentiates five patient profiles (A-E), ranging from patients who barely require any help, to patients who are bedridden (ArjoHuntleigh, 2013). With heavier patient profiles, the support that caretakers have to provide becomes increasingly taxing. It is important that they will not injure themselves, from heavy lifting for example. Support bars for the patient, or patient lifters can be can be a solution.

There is an increase in the use of self-diagnose devices. These allow the user to take small measurements themselves, without having to go to a physician. Examples of these devices are blood pressure meters, blood sugar meters and small chips that can measure all kinds of values (lab-on-a-chip). Caretakers can help with using these devices.

**MAINTENANCE & APPEARANCE**

Most bathroom users prefer a bathroom with a clean and healthy appearance. Cleaning is an important consideration in a bathroom, as bathrooms are notorious for being difficult and tedious to clean. Any trace of calcification or mold can shatter the image of a clean and healthy bathroom.

To ease the process of cleaning, the objects in the bathroom should be accessible. A smooth finish to the bathroom surface is preferable. The water that has been used for washing can easily drip off a smooth surface. If the water is able to stick to the wall or remain in a seam, it may lead to the growth of bacteria. Calcification is common on hot surfaces, as a result of water evaporation. On cold surfaces there is a risk for condensation. In some situations this can cause dripping water at unwanted locations.

The surface of the wall panels of the IDF bathroom is smooth, so they can be easily cleaned and to ensure the water can flow down. There are only a few seams
between adjacent panels. Users want to be able to choose their own surface finish. This is possible in later iterations of the IDF bathroom, but for now there is only one wall panel type. The ducts and pipes are concealed behind the wall panels. This offers aesthetic comfort and makes it easier to clean, as it might be difficult to reach behind pipes that are mounted on the front side of the wall.

Sometimes other maintenance activities, such as the replacement of leaking seals or unclogging a clogged shower drain, have to be carried out. A clear access path to the relevant component of the system is required. It is however difficult to reach components that are inside of the IDF wall. Components with a high risk of failure should be placed at accessible locations.

**LEGAL REQUIREMENTS**

Every installation in the bathroom is subjected to legal requirements. The Dutch requirements can be found in the building act: het bouwbesluit (“Bouwbesluit online 2012,”). In many cases the building act refers to regulations in installation specific documents. For example, the guidelines for electrical installations are described in NEN 1010. These regulations are described in more detail in the separate installation sections (refer to section 3.4).

### 3.3 Flexibility requirements

The IDF bathroom is designed to be very flexible. But what does that mean? There were four types of flexibility in a building. In a bathroom the same types of flexibility apply: partitionability, adaptability, extendibility and multi-functionality. This section explains how these types of flexibility can be found in the IDF bathroom.

The IDF bathroom will not remain the same during its lifespan. The fixtures can be switched around, but it is also possible to add new fixtures. For home use, some users may want to place the washing machine or dryer in the bathroom. They may prefer to have another sink (or another tap in the sink). If the IDF bathroom is used in public toilet areas, there can be a need for additional toilets. These additions are related to the installations. To be able to connect fixtures in the future, there need to be enough junctions available.

Partitionability does not apply to the IDF bathroom. It is a type of flexibility that is relevant to the whole building, and not to a specific room in the building. In the case that rooms in the building get repartitioned, the size of the bathroom will change. For the bathroom this means that it will get extended (or downsized). This can be solved by the addition (removal) of a module. It is likely that during a reconfiguration of the rooms in a building, the IDF bathroom will be temporarily removed.

The user wants to be able to control the systems in the bathroom. For this reason those systems need to be adjustable. The brightness of the lights for example. There are also systems that need adaptability just to function properly. The wastewater installation for example requires a slope. This means that it should be possible to adjust the height of the wastewater pipes. Many home automation systems have some sort of adaptability built in.

Multifunctionality is the key to variation. All the wall panels are mounted in the same way. This makes it possible to design additional wall panel types. It also applies to the location of support brackets.

The IDF bathroom should be able to handle the following scenarios:

- The installation & removal of the bathroom
- The reconfiguration of wall panels
- The replacement of a fixture
3.4 **Installation Requirements**

To design a functioning bathroom, five installations are required: the water installation, the wastewater installation, the electric installation, the ventilation and a heating installation. The installations are subject to legal regulations. It is also important to understand how the installations are implemented in buildings ‘normally’. This can give some valuable insight to how the IDF bathroom can be designed. The installations of the IDF bathroom are a part of the installations for the whole building. To be compatible, it is important to understand what a common setup is for the installations in the building. This project adds a sixth installation: the data installation. This section describes these six installations.

**Water**

The water installation of the bathroom transports hot and cold water to the fixtures: the sink, shower, bath and toilet. It includes all of the pipes that run from the bathroom wall to the fixtures.

Warm water can either be heated centrally or locally. Most resale properties have their own local boilers. However, many apartment buildings use central water heating. In that case, all apartments share a single boiler. A circulation pipe continually circulates water past the boiler and past every apartment. Tap lines branch off from the circulation line into the apartments. The shorter the tap line is, the faster the tenants have access to warm water. For maximum comfort the circulation line should run through the bathroom. This is important for the material choice of the pipes, as the water temperature in the circulation line is at least 60-70°C. Copper and Wicu pipes are resistant to the water temperature. The use of standard plastic pipes in this situation is ruled out.

The water installation should be designed in a way that limits the growth of Legionella as much as possible. The Legionella bacteria can cause the Legionnaires’ disease. It is an infectious respiratory condition that can be lethal for people with weak immune systems, elderly in particular. Legionella grows best within stagnant water of 25-45°C. Cold water pipes must be kept below 25°C. They should be kept away from any external sources of heat. This includes the circulation lines, radiators, floor heating or in some cases the apartment below. Hot water pipes should be able to quickly cool down. They need sufficient ventilation. It is recommended to keep the hot and the cold water pipes as far from each other as possible.

In addition to temperature problems, water is also not allowed to remain stagnant. For this reason sections of blind pipe (pipe that doesn’t lead anywhere) are against regulations. The guidelines to dealing with Legionella can be found in the guide (ISSO, 2012). It is also possible to use software to calculate potential issues with hotspots.

Water pipes often have a shell. Hot water pipes can be insulated to prevent heat loss. Cold water pipes are prone to condensation, particularly in a humid bathroom. Condensed water on a pipe may cause problems. A layer on the outside of the cold water pipe can prevent this. Additionally, an insulation layer can slightly reduce the noise of the water.

Water hammer is another harmful effect in the water installation. Water hammer is the knocking sound that can be heard when a water faucet is suddenly closed. Ceramic faucets especially can cause water hammer. When this happens, the pressure in the water pipe quickly rises, and it may result in a violent shaking. Water pipes should be sufficiently fastened to prevent them from hitting the wall during water hammer.

**Availability**

Water pipes can be made of roughly three materials. The most traditional pipe is a copper pipe. Copper pipes have been applied in many projects before. They are resistant to hot water and very strong, but
the strength makes it difficult to create corners. This means that relatively many connector pieces have to be used. Increasing copper prices make this an expensive option, especially in the future. Plastic pipes are an alternative to copper pipes. Although they cannot withstand hot water as well as copper pipes, they can be more easily bent. This means that fewer connectors are required. Flexible pipe doesn’t appear as sleek as copper though. The third category contains layered pipes. The layers aim to remove the drawback of the original. Examples of this are WICU pipe or plastic barrier pipe.

Branches in a water pipe have to be made with T-connector. This cannot be done afterwards (without much adaptation work), so branches have to be planned in advance. Connectors can either be permanently fixed to the pipes (glued, soldered, electric welded, etc.), but there are also versions that can be detached at a future date. Afterwards they can be reused in most cases.

Requirements:

- Standard plastic water pipes should only be used for tap lines (and not for circulation lines).
- Cold water pipes should be separated from external heat sources.
- Hot water pipes should have enough room to quickly lose their heat and cool down to below 25°C.
- All water pipes that are larger than 5 times its diameter should lead somewhere. (blind pipe is not allowed)
- Cold water pipes should be protected from condensation if condensation could result in problems.
- All water pipes should be sufficiently fastened. At least every meter and within 15 cm of corners.

**Wastewater**

The wastewater installation of the bathroom collects the wastewater from the fixtures, and transports it to the building ground pipe. The wastewater is collected from the toilet, shower and the sink. All the pipes between the fixtures and the drainage point of the building are included in this system.

Each pipe in an indoor plumbing installation seems to have a different name. There are ground pipes, down pipes, relief pipes collection pipes and connection pipes. The wastewater from the fixtures comes through connection pipes into a collection pipe. The collection pipe transports the water to the down pipe. An air relief pipe is used to prevent vacuum in the pipe, while the water is flushing. The air relief pipe is often connected to the down pipe. Pipes that lead further away from the down pipe may require an additional air relief. All horizontal pipes in the wastewater installation are installed with a slope. This makes sure that the water can flow downwards naturally.

One of the goals for the IDF bathroom is that all of the installations are put inside the wall. This makes sure that the installations can be accessed at a later date. The wastewater system has problems with this. While the drain of the sink and the toilet can lead through the wall, the shower drain cannot. A shower tray raises the drainage point, which might make it possible to install drainage pipes. Alternatively a pump can be used to mechanically drain the wastewater. Both of these options have some drawbacks. A shower tray would be inaccessible to people with a wheelchair. Pumps need maintenance and may break down.

In renovation projects, the connection of the wastewater system to the building can be problematic. The existing drainage point might be in an inconvenient location. Depending on which type of toilet was installed in the old situation, the drainage point could be in the floor, 20 cm from the wall. It will be very difficult to connect a wall system to such a drain. The most preferable location for the old drain is in the...
To prevent nasty sewer smell, each fixture is connected to a water seal. Every time when an upstream fixture is flushed, the pressure in the pipe behind the water seal drops. On critically low levels the water is sucked out of the seal, which opens the way for sewer smells. An air relief pipe can be used to prevent the pressure drop in the pipes. Another useful guideline is to have a proper distance between the locations where connection pipes branch off of the collection pipe.

Sometimes the indoor plumbing is located near a bedroom or living room. In these cases the noise of flushing wastewater can be a nuisance. Special plumbing exists that mitigates the noise of the water inside.

Availability

Wastewater pipes are made from some kind of plastic. PVC is the most common material for this, but PE, PP and some others can also be used. These materials are very rigid. When the pipe needs to go around a corner, a special connector piece is required. There is a huge availability of connectors available. While flexible sewage pipe exists, it is recommended against.

Branches can be made with T-connector pieces. The connector pieces can be chemically connected to the pipe. This creates a strong rigid system, which does not allow for any flexibility in the future. An alteration to a pipe requires that the pipe section is sawn off. Alternatively the connectors can be equipped with a rubber cuff. These do not require additional fastening methods, but they are more expensive.

Those connectors allow for repairs and expansions in the future.

Requirements:

- Wastewater pipes should be installed with a slope of at least 0.5% (5 mm/m).
- The shower drain should be connected to the wastewater system.
- Keep sufficient distance between the connection pipes (1m is sufficient most of the time).

Electrics

The electric installation provides power to the electric devices, such as power outlets, lights, etc. Light switches and other control devices are part of the data installation.

Bathroom users have a few products that require power. Electric shavers and toothbrushes need to be recharged, and hairdryers often need to be plugged in. For this reason they desire a power outlet in the bathroom. Most of these products require a 230V connection. There are some alternatives that use a lower voltage (12V), but those devices do not have the same performance.

The use of electric power in the bathroom can be dangerous. Modern houses and apartments have a 30mA residual-current breaker. When the outgoing current is more than 30mA less than the ingoing current (short circuit), the system shuts down. Older houses do not always have a safety like this in place. With a 30mA current breaker, most of the safety regulations are met.

The regulations that apply to the electric installation are described in NEN 1010. It has a specific section dedicated to electric systems in the bathroom. According to the regulations a bathroom is divided into four zones. Each zone has specific safety regulations (NEN, 2009). Cable systems that run behind the wall bordering zone 0, 1 or 2 should be recessed at a minimal depth of 5cm, unless it is a 12V system or unless it is protected from mechanical penetration. Taking the above into account it is safe to
adopt a degree of protection of at least IPx4 for all electric bathroom equipment.

High power devices (over 2kW) should be installed in a separate power circuit. I.e. the circuit should have its own circuit breaker and no other devices are allowed on the circuit. The addition of a washing machine (2.4 - 3.2kW) means that an additional circuit would have to be installed, which includes drawing a new cable from the meter box to the bathroom. The electric system in the bathroom would then have a second main power cable. It is useful to reserve extra space for a second power connection, in case any additional high power device is added later.

Availability

The electric installation is very flexible, easily the most flexible of the bathroom installations. Because it is so flexible, it is important that the connections are made properly. Color coding is often used to make a distinction between multiple wires. Special plugs are an alternative to ensure a correct connection.

Branches can be inserted at any location. Wires can easily be cut and with a connector block the branch can be attached. There are also cables that allow for a branch connection anywhere on the cable. These can just be added afterwards, without having to cut the cable. Additionally almost all electric cables and wires can be reused.

Requirements:

• Comply with the NEN 1010 regulations.
• Bathroom equipment should have an IPx4 degree of protection.
• Electric cables should be recessed 5 cm into the wall.
• Reserve space for additional electric equipment.

Data & Bathroom Automation

The data installation is the system that controls the bathroom. It communicates with the users and controls the intelligent systems, including home automation. In care homes the data system can be used by caretakers to look at the medical file of the patients. A display can indicate which medication is required, and which care the user should receive. Other applications for...
home automation include comfort, safety and sustainability reasons.

User comfort can be increased by smart application of home automation. A time sensor can warm up the water in a bath, right before the user wakes. A CO2-sensor in the ventilation duct can measure when the fan should be activated, so the user does not have to remember to manually enable/disable it. Smartphones can be used as a remote control to turn on the heating in advance before users enter their home. A communication device can indicate what the weather is, at the moment users are styling their hair.

Home automation can also be used to increase the safety in a home. A sensor can detect the height of the water in the bath and act upon it, to prevent overflow. A sensor in the faucet can measure the output temperature of the water, to warn the user when the water is too hot to use. Some systems are able to warn others in case of an emergency when for example the user slips and doesn’t get up.

There are some measures regarding home automation that can be taken to increase the energy efficiency of buildings. For example, the lights can be automatically switched off when there hasn’t been any activity in the room. A time sensor can disable the heating at preset times (when the user is at work/in bed). The amount of used water in the shower and sink can be dosed to save on water. Recharging electric devices/washing clothes can be automatically done at night, during off-peak hours.

In the IDF bathroom the data system is initially limited to the control of the lighting. However, it should be possible to add upon this system. Often these systems have some kind of wireless system, so they can easily be installed, without removing the wall panels.

Requirement:

• Reserve space for the implementation of home automation.

VENTILATION

Good ventilation is especially important in a bathroom. Moist air should be vented from the bathroom. The removal of smells increases user comfort. Air extraction can be achieved with a mechanical fan. It can be placed somewhere centrally in the building, or de-centrally in the bathroom.

Ventilation systems can be divided into natural (passive) and mechanical (active). There are four ventilation scenarios: fully natural (natural supply, natural exhaust), fully mechanical (mechanic supply, mechanic exhaust) or a mix of both.

Natural ventilation is preferable to mechanical; it works with pressure differences. Natural pressure differences limit the amount of ventilation is limited by the air flows in the home. A bathroom or kitchen requires more ventilation than naturally happens. Mechanical support ventilation is then required. The scenario of a natural supply of air, combined with a mechanical exhaust is common in many residential houses and apartments. A fully mechanical ventilation scenario is also possible. In that case, fresh air is actively supplied to the living areas of the apartment: living room, bedroom. The pressure in these areas increases, causing the air to flow to the exhausts in the bathroom and kitchen. Both scenarios have similar requirements of the bathroom. The air comes in passively and is exhausted mechanically.

The Dutch building act decrees that 14 liters of air per second should be exhausted from a bathroom. With an exhaust speed of 3-4m/s, this means that the sectional area of the duct should at least 3500-4600 mm2. More air can be exhausted if the exhaust speed is increased, but that would also cause an increase in noise. The generated noise by flowing air is proportional to the third power of the speed (Schalkoort, 2009).

Availability

Ventilation ducts are fairly large. It is not a very flexible system. Ventilation ducts
are either made of aluminum or PE. These materials don’t contaminate the air (that is why there are no PVC ducts). The general ducts are not flexible. Corner pieces are available. There is a special type of ventilation duct that is flexible. Using the flexible air duct cause a large pressure loss. Flexible duct should only be used if there is no other option, and only for small distances.

Branches in the ventilation system can either be made with T-connector pieces, or by cutting a hole in the duct. The ducts are often sealed with some kind of kit. This makes it difficult to quickly change the layout.

Requirements:
• Exhaust 14 liters of air per second from the bathroom.

HEATING

The heating system provides heating to the bathroom. There are a few possibilities for the release of heat into the bathroom. There is a choice between floor heating, a radiator, an IR-panel and more. Floor heating results in a pleasant heat gradient in the bathroom, but it has to be placed inside the floor. This is difficult to achieve in a modular wall. IR-panels emit heat that can be directly felt on the skin. Radiant heat only heats objects that it radiates on. This means that moist in the air doesn’t evaporate as quickly as with other system. Radiators offer a mix of radiant heat and convectional heat. The drawback is that they take up a lot of space.

Heat is preferably transported by water. The thermal capacity of water is higher than that of air, which means that it can contain more heat. Systems that use water as a heat transport medium can also be used for low temperature heating. Low temperature heating can be very efficient, as long as the heat release device has enough capacity.

There is some debate about whether electric heating is more efficient than heating with a boiler. The argument is that electric heating can be more easily turned on when the user is in the room. Thus saving energy based on user behavior. Technically electric heating can never be more efficient, because electricity is generated in power plants by burning fossil fuel, at an efficiency of below 60% (Enecogen, 2013; Nuon, 2013).

Availability

The heating installation uses the same components as the water system. The water that runs in the heating pipes does not have to be of drinking quality. Heating pipes can be made of iron, which is much cheaper than copper. Barrier pipes can also be used. An aluminum layer in the barrier pipe ensures that oxygen cannot get inside the heating pipes. Oxygen can be harmful to metal components, in the boiler for example.

SUPPORT SYSTEMS

Besides installations, there are two other important systems in the bathroom that shouldn’t be forgotten. These are the load-bearing and the wall finishing.

A traditional bathroom uses the building wall for loadbearing. The plumbing and pipes are mounted on or in the wall. The fixtures are supported by the wall, and the bathroom finish is also stuck to the wall. This way, the loadbearing, the installations and the finishing have become one single object, with multiple functions.

According to the IDF view, multiple functions can only be successfully provided by multiple objects. The loadbearing structure should be decoupled from the installations, and from the wall finishing.

The finishing system has both a protective and an aesthetic function. It should prevent water from getting inside of the IDF wall. Ideally it is not attached to anything other than the loadbearing structure.
In rare occasions a flash of inspiration by the designer results in a brilliant product solution. It is often more successful to rely on a method instead. The design of the IDF bathroom is done in a few stages. It starts out with the design of a general structure. This structure makes sure that the desired flexibility can be achieved. Later stages get into the details of the installation of the system, and how the design deals with the availability of components. The final design step contains the details, such as pipe attachments, etc. A 3D model helps to explain.
4.1 Basic Structure

The first step in the design is to create a basic structure for the installations. It takes the current IDF bathroom structure as a starting point; a metal frame carries the loads of the installations. The space inside the frame is reserved for the installations. At some point, the installations branch off to the fixtures. Three specific zones are defined: a static section, a variable section and a building connection section.

Some buildings provide ventilation through the ceiling, while others do it via the wall. A single solution is thus not always possible. Some exceptions situations are highlighted throughout this chapter.

The basic structure has some exceptions. They are caused by specific requirements, regulations or practicality. In the case of the water system, regulations prohibit large sections of blind pipe. The wastewater system is also a good example of an installation that has specific requirements that interfere with the basic structure. The wastewater installation requires a slope, so there need to be some readjustment possibilities in the basic structure.

Installation Panel

The initial design of the IDF bathroom features a wall panel that is separated into three pieces. A main panel that stretches along the major area of the module and two smaller separate panels (let’s call them installation panels). These installation panels can be detached separately from the main panel. The idea behind this is that small changes to the installations can be made by removing the small panels, instead of having to remove the main wall panel. This increases the flexibility of the system as a whole. The prototype of the IDF bathroom included two installation panels, but the results were disappointing. It proved to be difficult to attach the panels...
to the metal frame, due to a rubber sealing strip. Because of this, it seemed preferable to omit the installation panels all together. The question is whether this is feasible or not.

There are two possibilities; either the wall panel consist of a single panel, or it consists of multiple panels. It is not so easy to determine which is best. The choice does not only determine the flexibility of the bathroom, but it also alters how the bathroom needs to be installed and what it will look like. It can be said that the choice determines what the complete installation layout will look like.

Regarding flexibility it can be easily seen that the inclusion of installation panels is a good thing. The panel is used as an access point to the installations. The electric installation in particular benefits strongly from the increased accessibility. An addition to the electric system (for example if the user wants to install an extra lamp) can be made while the main wall panel remains in place. It also becomes possible to easily add a washing machine, for example. In addition to flexibility, the installation panel enables the possibility to repair and replace parts of the installation (although it is unlikely that something needs to be repaired).

The application of an installation panels creates an extra seam. Some users may find the extra seam aesthetically unpleasant. It is difficult to hide the seam from vision, but it may instead be used to give the bathroom identity. Some examples of this are shown later in the report. A drawback of an extra seam is that it increases the cleaning effort. One of the starting goals has been to make a bathroom that is easily cleaned. However, compared to a traditional bathroom wall finish, it still isn’t too bad.

The installation of the ‘stuff’ behind the wall is the third consideration. Whether or not the installations can be accessed through an installation panel particularly determines what the connection between main pipes and the branches will look like. This mainly is related with the attachment system of the wall panel to the frame. The next section elaborates more on this.

In conclusion, there are both benefits and drawbacks to the use of an installation panel. Because the omission of an installation panel completely changes the layout of the system, two concept solutions have been created. One of them uses an installation panel and the other one doesn’t.

**Concept solutions**

The first concept is the Duopanel concept. It includes installation panels. In the Duopanel concept the installations in the variable section are attached to the back-side of the panel. This ensures that the pipes are firmly secured. The dependency between the movement of the panel and pipes is broken. The issue points shifts to the connection of branch pipes with the main pipe. The location where the pipes penetrate the panel can be sealed in advance, which saves time on-site.

The installation of the Duopanel concepts starts with the placement of the frames. Secondly, the main pipes of the installation are attached to the frame. Then the connection to the building is made. Next, the wall panels are mounted on the frames and the connection between main pipes and the branches. Finally the installation panel is attached. It is possible to pre-equip the wall panels in the Duopanel concept with fixtures, but that seems somewhat risky and unpractical for transport.

The second concept solution is the Singlepanel concept. As the name suggests it features a single wall panel; omitting the installation panel. In this concept the installations in the variable section are mounted to the frames. To attach them, an extension to the frames is required. The installations are completely separated from the wall panels, but that does not mean there are no dependencies between them.

The installation of the Singlepanel concept starts with the placement of the frames. Next the main pipes are installed. They are then connected to the building. After
that branch pipes of the installations are mounted to the frame. After the panel has been put into place, the installations can be connected to the fixtures.

**Installation comparison**

The attachment of the frames to the building wall is the most time-consuming step in the initial installation of the IDF bathroom modules. It requires a high degree of precision, so the readjustment process will be tedious. Fortunately the frames can remain in place when changes are made to the system. This step takes the same amount of time regardless of the choice of concept. The Singlepanel concept requires additional steps of attaching the flexible section to the frame and sealing the panels afterwards. The Duopanel concept requires the attachment of the installation panel, which might also include sealing the panel. If a seal is included in the installation panel, then the Duopanel concept can be installed faster.

The largest difference is how the branch pipes are connected to the main pipes (step 4 and 6). In the Singlepanel concept these can be easily connected to a T-junction. However, in the Duopanel concept an additional component is required to make this connection. That component has to be pried between the main and the branch pipe, which may be difficult. However, with proper design, it does not necessarily require more installation time.

**Flexibility**

The Duopanel concept is more flexible than the Singlepanel concept. That is its big plus. The ability to take away only a small section of the wall panel allows much more easily for changes. In the Singlepanel concept for every change (however small) the whole panel needs to be removed. This is a hassle; it includes removing the fixtures, and the resulting holes need to be resealed. For example, let’s assume that the user wants to install an additional lamp above his/her mirror. This can be done in the Duopanel concept without removing the whole wall panel. A small hole is drilled in the panel where the lamp is to be located. A power cord is inserted in the hole and extended downwards behind the panel. The installation panel is removed and the cord can be connected with the main electricity cable.

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**Figure 23:**
Two implementations of the interface between the installation and the wall panel, and between static and variable section of the installation. On the left side is the duopanel concept. On the right side is the singlepanel concept.
4.2 **Final design**

The final design for the IDF bathroom is based on the structure of the Duopanel concept from the previous section. That means that the branch pipes are attached to the back of the main wall panel before it is mounted on the frame. For each installation, the following details have been developed:

- The location of the main pipes within the frame
- The attachment of the main pipes with the frame
- The connection between the main pipes and the branch pipes
- The penetration of the branch pipes through the panel
- The attachment of the branch pipes to the wall panel
- The connection of the main pipes with the building

**Water installation**

The top area of the frame is reserved for the water system. The warm and cold water pipes are separated from each other to prevent Legionella growth. The warm water main pipe is located in the front, near the panel. The cold water main pipe is located in the back. Barrier pipes are used for this section. An installation rail is mounted against the frame. The water pipes are installed on the rail with clamp saddles.

Near the middle of the water pipe is a T-junction. This junction makes it possible to connect a branch pipe. In the last module that requires a water connection (i.e. the module that is furthest away from the building connection) half of the water pipe is omitted. A water pipe that doesn’t lead anywhere is against regulations.

The branch pipes are mounted to the back of the panel with clamp saddles. At the top end, they are connected to a wall plate. The wall plate is a bracket that keeps the pipes

**Figure 24:** Various solutions for the interface between the water system and the building.

**Figure 25:** An image of the bottom section the installation concept.
at a specific distance from each other. Since the shower tap is directly connected to the wall plate, the exact distance is important. For the shower the distance between the pipes is 150mm, for a sink it is 80mm. This variation means that the location of the pipes is not exactly the same every time. To neutralize this, the branches are connected to the T-junction of the main pipe with a flexible hose. A flexible hose is also more easily connected.

The location of the water installation with the water installation of the building is specific to the building. The connection could be located on any wall in the bathroom. This makes it difficult to have a standard solution for the connection of the water system to the building. A flexible pipe is useful in this situation. The length of the pipe and the type of connectors that are used (T-connector, elbow connector, etc.) are situational. In some cases the pipe needs to split into two directions (one for each wall in the corner). An additional T-junction in the corner section takes care of this. A valve is placed at an accessible location to be able to close off the installation. As much as possible of the flexible part of the connection of the building should be located in the corner. This makes sure there is little interference with the other system in the modules.

**Wastewater System**

The body of the wastewater system is similar to the water system. Each module that needs water also needs a sewage connection. The wastewater system consists of a main horizontal pipe that transports the wastewater to the down pipe. Each module has a T-junction. The junction has not been placed in the middle of the module. Instead it is off centered. This results in more space for the connection with the branch pipes. However, the shower drain does not go inside the wall.

The main plumbing is sizeable. Considering the junctions it barely fits in the frames. For this reason it is placed in the middle of the frames. This allows the water pipes of the water system to move left and right alongside the wastewater pipes. To guarantee a homogenous slope of around 5mm/m, the wastewater plumbing is made of rigid PVC. There are alternatives to PVC, such as PP. The plumbing is suspended at the location of the installation rail. At both ends, the height of the suspension brackets can be tuned, to create a slope.

The vertical branch pipes are fixed to the panel. Like the water system, they can be detached during transport. The diameter of the vertical plumbing differs depending on the function of the particular module. A toilet requires 110mm, the sink and a washing machine can do with 40mm. The T junction of the main pipe is always 110mm,
so a transition sleeve is required when dealing with a 40mm pipe. The connection can be made through the bottom installation panel.

The shower drain remains a problem. There is not a suitable wall solution for it. A possibility would be to extend the IDF bathroom with floor panels. The shower drain could then be easily installed at any location in the floor. However, floor panels are beyond the scope of this project. The advice is to use the old shower drain if there is one.

The wastewater system needs to be connected to the down pipe of the building. Depending on the location of the down pipe one of two connections is used. The preferred method is when the down pipe is accessible and close to the bathroom. The system is then connected with a ball connection. The ‘ball’ makes sure the wastewater has enough space to flow away. It is also possible that the building drain pipe enters the bathroom horizontally (with slope). In this case an alternative method can be used to connect the wastewater system. The connection is made at a 45 degree angle to help with pressure relief in the pipe. Note that in the second scenario there is no space for a drain in the most downstream module.

**Electric System**

The electric system is the most flexible system available. The cables for the electric system can be bent in any direction and with the use of flatcables it is possible to create a branch at every desired location. The electric installation provides power to the lights, power outlets, data system and all user installed electric devices and home automation.

The electric system makes use of the GST18 building automation standard. This is a standard for electric plugs, cables, distributors, etc. The plugs are safe and can only be plugged, in the correct way. This standard offers good flexibility and is perfectly suited for this project.

The electric installation has two main horizontal cables. One is located in the top frame, and one in the bottom frame. The flatcable is located in the far back of the module to prevent injury from mechanical penetration (for example when a hole

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**Figure 27:**
A possible implementation of the connection between the wastewater installation and the building.

**Figure 28:**
Some components that are used in the wastewater system. From left to right: a PVC T-junction, a PP ball connection and a suspension bracket.
is drilled in the wall). It is held into place with support brackets in two locations. Both cables have 3 phase wires that it can use. For example one can be used for the lights, one for the outlets and the third can be reserved for future expansions. It is possible to put different electric circuits on the same flatcable, so it is possible to connect a washing machine to the 3rd phase wire. The branches can be made with special connector blocks.

The cable is accessible through the installation panel. For example, when the user wants to add additional lighting, he can drill a hole in the wall panel where he wants to place the lamp and lower a GST18 cable through the hole. The cable is then collected in the bottom frame and easily connected. The frame has additional brackets for the installation of additional electrics. This needed when the user wants to add equipment that cannot be connected to the available system.

The lights are controlled by a wireless PIR sensor on the ceiling. The PIR sensor sends a signal to a switch box. There the power of the specific phase wire is controlled.

**Ventilation system**

The components of the ventilation system themselves are not very flexible. The ventilation system is comprised of a main air duct with junctions in the middle of every module, behind the top installation panel. The junctions are closed with a removable end stop. It is possible to make a ventilation grill in the top installation panel. The duct is supported by the metal frame at two locations per module.

Ventilation is not required in each module. Only one connection per bathroom is required. It is likely that the ventilation connection is on the same location as the shower. For this reason the ventilation system could be omitted from a few modules.

The use of rigid ventilation ducts is preferred over the use of flexible ventilation ducts. The internal ribs of a flexible duct cause a high loss of pressure. For this reason, the static part of the ventilation system has rigid ducts. However, for the connection of the ventilation system with the building a flexible duct is preferred. The flexibility in this case is useful because there is no standard location for this connection. A flexible connection is suitable.
for when it is not clear in advance where the connection will be.

**HEATING SYSTEM**

In this design, the heating of the bathroom is done with radiators. Floor heating is possible, but it would reduce the roll of the IDF wall module in this regard. The radiator needs a supply pipe and a return pipe. The heating system is very similar to the water system, but instead is located in the top modules. It consists of a main pipe for supply and one for return that transport the water across the modules. Branch pipes connect to junctions in the main pipe. They are connected on the back of the radiator panel.

**DATA SYSTEM**

Data systems need power and the availability of data. Modern data systems will almost always be wireless. This means that there will be no additional cable required for the transport of data. Although data cables are likely not required, it is still possible to add them later, because there are additional support brackets. The power for the interfaces can be provided by the electric system.

Home automation can be built in the IDF bathroom. To control home automation, there needs to be an interface for the users. This could go via a central panel that controls all the systems. It may be possible to control the bathroom in the future with your mobile phone.

**MOUNTING THE FIXTURES**

The bathroom fixtures need to be connected to the IDF bathroom, to a loadbearing element. Usually this is done with two threaded rods. The position of these rods is standardized among most fixtures. For example, the center to center distance of the rods for a sink is 280mm in most cases. Because of the standardization, the holes...
The shower tap can be directly connected to the hot and cold water pipes that penetrate the panel. These pipes end in a thread. The shower tap can be screwed on this with some tape to prevent leaks.

The toilet requires a different approach. Just like the sink, the attachment of the toilet is done with two threaded rods. However, the toilet weighs a lot more than the sink. At the moment the wall panels are not strong enough to bear the loads of a toilet in use, without bending significantly. This might change in the future, if the panels are developed further. For now it is safe to assume that the toilet cannot be suspended off the wall panels.

The rods for the toilet can be mounted on the IDF frame. Because the frame is 360-380mm from the ground, it would result in a high-seated toilet. This may be nice for elderly people who prefer the height, but for others it may not be very comfortable. With this method it is not possible to adjust the height of the toilet. Until the development of the frame has reached a point where it is more flexible, the toilet will be suspended by a prefab toilet suspension frame. These are often used in bathrooms. The advantages are that it supports the toilet and also has a built in water reservoir for flushing the toilet.
Evaluation
## 5.1 Lifecycle assessment

This chapter compares the IDF bathroom with the traditional bathroom on an environmental basis. An LCA analysis is made to answer these questions: Is the IDF bathroom better for the environment? Which conditions make the IDF bathroom a better choice with regard to the environment? Or to be more specific: How often does a (traditional) bathroom needs be remodeled before an IDF bathroom is better for the environment.

### Assumptions

As previously described a full LCA analysis is a lengthy process, which requires many assumptions. Likewise for this analysis the following is assumed:

- The analyzed bathroom measures 3x2 meters and features a bath with shower, a sink, a toilet, a radiator. For the IDF bathroom this means that it uses a shower module, a sink module, a toilet module, a radiator module and an empty module. The modules require no bathroom space, as the value of bathroom space is difficult to determine.
- All bathroom fixtures have not been taken into account, as they are the same for both bathrooms.
- The water pipes and the electric cables are hidden in the wall for the most part in the traditional bathroom. The process of cutting slots in the wall and the material to fill them again is taken into account.
- The IDF bathroom is ventilated near the toilet and shower. The traditional bathroom is ventilated less ideally near the installation shaft. It would not be a fair comparison if the traditional bathroom would be ventilated on those positions, as that would not be a realistic option. Concealed ventilation ducts in the walls of the traditional bathroom would result very favorably for the IDF bathroom.
- Likewise the wastewater pipes that are located in the floor of the traditional bathroom are not taken into account. The shower drain in the IDF bathroom is also not taken into account. Pipes are put in the floor during the construction of the building. Concrete is poured around them, fixing them in the floor. Either both bathrooms can use existing floor drains, or both have to be put in from scratch.
- The lifecycle of the bathroom are assessed with the ReCiPe environmental assessment method. The hierarchist version is assumed with European normalization factors and average weighting factors.

### Results

The first interesting conclusion is that the assembly (which contains all of the processes and materials to put the bath-
The IDF bathroom has a much higher environmental impact than the assembly of the traditional bathroom. Upon further inspection, it seems that the wall panels are the major contributor. The wall panels are modeled as solid objects made of 60% wood fibers and 40% rape oil. These are the most important components in a bio-composite material. Note that a large portion of the environmental impact stems from the Agricultural land occupation mechanism. If epoxy resin is considered instead of rape oil, the environmental impact increases by approximately 25%. Other notable contributors are the metal frame box, the brass fittings and the electric cables.

For the traditional bathroom, the tiles on the wall are the major contributor to the environmental impact. The wall tiles and the IDF bathroom panels are made from a large mass of material. If it is possible to reduce the amount of material, the impact could be significantly decreased.

The next step is the addition of waste scenarios. What happens with the materials when the bathroom is dismantled? Materials can either be threshed or they can be reused. The reuse of the major impact contributors is considered. For the IDF bathroom this means the reuse of the wall panels and reuse of the metal components: the frames, the brass fittings and the copper pipes. It is assumed that the tiles of the traditional bathroom cannot be reused, so the only reuse considered is the brass fittings and the copper pipes. This equates to negligible reuse for the traditional bathroom. Three scenarios are considered: 100% reuse, 50% reuse and 0% reuse. It is assumed that 5% of all materials get threshed before reuse.

From the lifecycle assessment can be concluded that the IDF bathroom has a bigger negative environmental impact if the components (the wall panels in particular) are not reused. To have an equal impact as a traditional bathroom, 80% of the IDF bathroom has to be reused each time the bathroom is transformed. This means in the example bathroom, that for every new installment only one of the five panels is allowed to be replaced with a new panel. Alternatively it means that the IDF bathroom should last five times as long.

**Figure 35:** A comparison of the components in the IDF bathroom and a traditional bathroom. The graph only shows the components that have the largest negative environmental impact.
5.2 Prototype

To test if the design works in practice a prototype is made. The creation of a prototype can reveal problems that have not been thought of in the design and inspire improvements.

The prototype features a toilet module and a sink module. A toilet module has the largest pipes, so it is best at determining if all the installations fit in the frame. It is also interesting because it integrates a prefab toilet frame. It can be determined whether or not the integration of the IDF frame with the toilet frame works well. The sink module is the best at showing how the pipes of the water system are connected. The prototype only features the bottom part of the IDF modules. This way, the observer can walk around it and get a good view of the system.

Alterations

The prototype is not exactly the same as in the design. The prototype is made with available materials. However, the way that the components are installed stays relatively close to the design. Composite panels were not available for the prototype, so they got replaced with MFD sheets. These have the additional advantage that they can easily be processed. The wall panels are mounted to the IDF frame directly, and not with the proposed suspension system of the previous IDF wall. The IDF frame has undergone some changes, to be able to support a prefab toilet frame. The front bar has been lowered, and an additional support bar is added. In a bathroom situation the support bar will not be required, as the toilets frame can be supported by the bathroom wall, or alternatively supported by the wall panel. It ensures that the toilet won’t tilt over when someone is sitting on it.
Some positive and negative issues have been observed during the creation of the prototype.

- The toilet frame fits well on the IDF frame. This is not surprising as the IDF frame was custom tailored to be able to support the toilet frame.
- Connecting the installation rail requires drilling a hole. This is time consuming and can be prevented if the holes in the IDF frame are drilled at production, or alternatively if the installation rail is welded to the frame.
- The access to the water pipes is limited. At some locations the opening of the suspension brackets cannot be aimed to the front of the module, because there is not enough space for it. This makes it difficult to install the water pipes through the bottom installation panel.
- The pipes are firmly attached. The combination of pressing pipes with a clamp connector works well.
- The wastewater pipes of the toilet slope in the wrong direction. This would result in residual wastewater that remains in the pipe. In practice the height that is required for the toilet wastewater system is higher than in theory. To solve this problem the toilet could be placed higher. (it is now installed at +1cm; a toilet for elderly is at +6cm)
6 Results and Discussion
6.1 Project results

The main goal of this project was to design an installation concept for the IDF bathroom; a bathroom that can be adapted to the changing needs of the user. Not only the ability to change is important, but more so is the ability to quickly and easily change. Additionally there is the goal to reduce the amount of waste at the end of the lifecycle of the bathroom.

A good IDF design starts with a good structural design. One that can be partitioned, extended, adjusted and is multi-functional. Has that been achieved? Yes and no. The installations can be easily extended. One branch can be added to each installation per module. For the electric installation multiple branches are possible. It is also possible to add new fixtures to the installations, such as a washing machine. There is some multi-functionality in the design, because of how the suspension works. The rails can be used to support other equipment in the future. Partitionability is not much of an issue at the scale of a bathroom. However, it is not possible to replace two wall panels with three smaller wall panels, for example. The installations behind the wall panels would be confused. Adjustability is present to some extend in the installations. The location of the installations can be slightly modified if it is required. This ensures that the installations can be placed in multiple bathrooms, that have different shapes.

One of the problems that are currently seen in building installations is that they cannot be accessed. The accessibility of the installations in the IDF bathroom varies. The parts of the installations that are behind the installation panels are fully accessible. However, there are sections that are located behind the panels. To change these it is required to take off the panel. While this is a hassle, it is not needed to demolish anything for it. With the proposed waterproofing of Gerben and Joris of the Saxxion University, it may not even be needed to reapply a sealant.

A good system should reduce the amount of dependencies between components. The design has been successful in removing the dependency between the movement of the wall panel during the installation, and the placement/connection of the installations. However, a similar dependency between the toilet frame and the wall panel has not been solved. To solve this dependency, the toilet frame would have to be integrated into the wall panel. Alternatively, the wall panel could be strengthened such that it is strong enough to carry the toilet itself. This may or may not be possible.

Not every bathroom is the same. This means that the connection between the IDF installations and the building installations have to be custom made every time. Therefore there is a dependency between the location of the installations (in which bathroom are they used), and the components themselves. This dependency can in some cases restrict the flexibility of the IDF bathroom. The toilet connection might be at an unfavorable location in the floor. The shower drain is another example. There is a dependency between the location of the shower drain, and the location of the shower. No solution has been found that resulted in a flexible shower drain. It might be possible to make a flexible shower drain if floor panels are included in the IDF bathroom. Floor panels have the additional advantage that it will be possible to add floor heating. Floor heating is popular, as it warms up the tiles, so the user doesn’t get cold feet. However, floor panels introduce a whole new set of problems. In particular the waterproofing and the floor finishing will be problematic.

The IDF bathroom can be fully demounted at the end of the lifespan. The biocomposite panels could be reused, recycled or possibly incinerated with energy recovery. All of the metal components (aluminum frames, brass water connectors) can be reused if possible, or they can be recycled.
The advantage of metal is that it remains a high quality material after recycling. The plastic components can be recycled, as long as they are made of a single plastic. However, the resulting polymers are of reduced quality. Composite products, such as barrier pipes and electric wire are difficult to recycle. In practice they are likely thrown away.

6.2 Discussion and Recommendations

IDF building does not only look at the functionality of the solution, but also at the technical side of the design. It is important that the modules can be produced in an industrial way and that the onsite installation time is low.

It is possible that the frame modules are factory-equipped with all the required installations. This decreases the onsite installation time. However, it is difficult to decide which installations should be in the initial frame. Some installations do not run into every module (water system). The access pipes either need to be removed, or closed off with a valve. Another disadvantage is that a lot of additional connectors are required. In the wastewater system there is little room for an additional sliding socket.

An alternative solution is to prefabricate the frames only with the installation rails and brackets. The pipes can be supplied to size. This can result in an installation package, which is customized to the bathroom of the individual. Because the installations are supplied with the correct sizes, the installation time will only be slightly longer. This is less valid for the installations that are mounted on the backside of the wall panels. Because a specific function has already been designated to a wall panel, it can be fully specified to that function. There should be no need for a toilet panel to be remade into a sink panel. It is undesirable if the users try to do that.

The individuality side of IDF building can be brought into the IDF bathroom through the distribution chain. The IDF wall panels could be marketed as DIY panels, just like products from IKEA. This would require that the installations can be installed by people without a technical background. Let’s say that someone has an IDF bathroom installed, and he wants a change. It would be ideal if that person could go to the store (or order it online), pick up a panel, and then install it by themselves. The substituted panel could even be returned to the store for some restitution of the purchase.

Panel Improvement

The results of the lifecycle assessment were surprising. The environmental impact of a wall panel is huge compared to any other component. The reason for this is the amount of material in the panel. It should be reconsidered if this amount of material is required. The strength of the panel might be high enough to not need this amount of material. It might be possible to blow air in the panel. This could give a nice visual effect. Alternatively the panel might be a compound of fiber board with biocomposite finish.

It is frightening that the IDF bathroom breaks even after five reconstructions. For a bathroom rebuild of 15 years, this means that the IDF bathroom should be installed for 75 years, just to break even. However, during this time, the users do have more flexibility. The amount of material that initially is used for the IDF bathroom is large. It also indicates that the material choice itself has more impact on the environment. This supports the need to reduce the panel weight, and the frame size.

In some cases the suspension of the wall panel resulted in problems. Maybe it would be a good idea if the wall panels could be installed in the same direction that the pipes go through the wall. The current design of the IDF bathroom has eliminated the dependency between the installations and the panel suspension, but if problems...
are encountered during future development of the bathroom, the direction of panel suspension may be reconsidered.

**Frame Improvement**

The prototype has shown that the IDF support frame needs some improvement. The frame that the project started with was too plain. It is a square box with little to no opportunity to attach anything to it. The frame that has been used for the prototype is not ideal also. It has been altered to fit with a specific prefab toilet frame. However, it is not a good idea to couple the design to a specific toilet frame. Every frame should be possible. Alternatively a toilet frame is not required at all. There are two routes that can be taken for further development of the IDF frame: the heavy route, and the light route.

The heavy route strengthens the frame. In this scenario the top frame and the bottom frame become one. The frame can be better placed against the bathroom wall. There is no hassle with the adjustment of the frames. The prefab frames of other manufacturers are replaced with frame additions that fit on the IDF frame. A toilet addition could be placed on the frame to suspend the toilet; A sink addition for the sink, etc. The fixtures are then directly supported by the frame. The frame additions require ample readjustment options, to adjust the height of the fixtures. This route requires that the frame is fixed to the building wall (floor/ceiling). A system like this would need a different mechanism to suspend the wall panels, because the wall panels move independently of the frame additions. An advantage is that the wall panels do not need to be as strong, so their weight can be reduced.

The light route changes the role of the frame. The frame will be reduced to the minimal size possible. It will act more like an adjustable bracket, than as a full support frame. However, it still carries the loads of the panel. The brackets are made on installation rail make sure that the installations have a suspension point. In this scenario, the fixtures are not directly supported by the frame brackets, but they are supported by the wall panel. The panels are reinforced to be able to bear the loads. The wall panels have to be designed carefully in this scenario, but it may be possible. If it is not possible, there is the option using the frame brackets together with prefab toilet frame from other producers. This saves in the development of components that the IDF group is less familiar with.

**My vision of the IDF bathroom**

It is not easy to say what the future of the IDF bathroom will look like. I think that the IDF bathroom is a good initiative that has the possibility to match the flexibility that the people want. I think that the aspect of being able to change your bathroom yourself is very important. You don’t want to every time call a mechanic to make easy changes for you, if you are just able to do it yourself. The IDF bathroom can help make these changes easy.

I think the first thing that needs to get improved is the frame. It does the job of designating a space for the installations, but it is not a suitable object to hang the installations on. The frame looks simple; an object that you place in the bathroom and afterwards you can hang a wall panel on it. However, this is not really the case. The frame needs to be carefully mounted to the wall/floor/ceiling. A small inaccuracy can cause skewed wall panels. Over the entire height of the panel, this can be very unappealing. In my personal vision the frame gets replaced in a similar fashion to the light route, as described above. Those frames would need readjustment.

I think the panels should be able to carry the loads of the bathroom fixtures. The material of the panel may be strong enough for this, but otherwise some metal reinforcement may be needed. There have been attempts to hide the seams between the wall panels. I would try to use the seams as a design element. By using colors or
shapes, the seams can be emphasized. This may create an interesting effect.

In my opinion the IDF bathroom is more suited to new buildings than to renovation projects. New buildings offer more possibilities. For example the IDF modules could be stand alone walls; with a wall panel and fixtures on both sides of the module.
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APPENDIX
# Appendix A: Design Requirements

<table>
<thead>
<tr>
<th>Theme</th>
<th>Need</th>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User needs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comfort</td>
<td>Visual comfort</td>
<td>-Low amount of seams</td>
<td>Only seams around wall panels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Small distance between seams</td>
<td>Seam distance &lt; 5 mm</td>
</tr>
<tr>
<td></td>
<td>Free choice of fixtures</td>
<td>-Smooth surface</td>
<td>Composite panel with resin finish</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Compatible with a large amount of fixture types</td>
<td>Mounting rods a ‘standard’ distance</td>
</tr>
<tr>
<td></td>
<td>Free choice of lighting/other electrical equipment</td>
<td>-Option to add additional connection to electric system above/next to mirror</td>
<td></td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>Easy to clean</td>
<td>-Low amount of seams</td>
<td>Only seams around wall panels</td>
</tr>
<tr>
<td></td>
<td>Replace sink</td>
<td>-Smooth surface</td>
<td>Composite panel with resin finish</td>
</tr>
<tr>
<td></td>
<td>Replace toilet</td>
<td>-Compatible with many types of sinks</td>
<td>Sink mounting rod HoH: 175-280 mm</td>
</tr>
<tr>
<td></td>
<td>Replace shower head/bath faucet</td>
<td>-Compatible with a large amount of fixture types</td>
<td>Toilet mounting rod HoH: 180 mm</td>
</tr>
<tr>
<td></td>
<td>Replace light</td>
<td>Accessible light fixtures</td>
<td>Use of existing solutions</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>A working toilet</td>
<td>Provide cold water to toilet</td>
<td>Ø 12 mm pipe from building to toilet</td>
</tr>
<tr>
<td></td>
<td>A working sink</td>
<td>Provide hot water to sink</td>
<td>Ø 12 mm pipe from building to sink</td>
</tr>
<tr>
<td></td>
<td>A working shower</td>
<td>Provide cold water to shower</td>
<td>Ø 12 mm pipe from building to shower</td>
</tr>
<tr>
<td></td>
<td>A working bath</td>
<td>Provide hot water to bath</td>
<td>Ø 12 mm pipe from building to shower</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide cold water to bath</td>
<td>Ø 12 mm pipe from building to shower</td>
</tr>
<tr>
<td><strong>Wastewater</strong></td>
<td>A working toilet</td>
<td>Drain wastewater from toilet</td>
<td>Ø 110 mm plumbing from toilet to building</td>
</tr>
<tr>
<td></td>
<td>A working sink</td>
<td>Drain wastewater from sink</td>
<td>Ø 75 mm plumbing from sink to building</td>
</tr>
<tr>
<td></td>
<td>A working shower</td>
<td>Drain wastewater from shower</td>
<td>Ø 75 mm plumbing from shower to building</td>
</tr>
<tr>
<td></td>
<td>A working bath</td>
<td>Drain wastewater from bath</td>
<td>Ø 75 mm plumbing from bath to building</td>
</tr>
<tr>
<td><strong>Heating</strong></td>
<td>Natural water runoff</td>
<td>Provide a slope in the plumbing</td>
<td>5 mm/m readjust able slope</td>
</tr>
<tr>
<td></td>
<td>Pleasant temperature</td>
<td>Desired temperature</td>
<td>20°C temperature</td>
</tr>
<tr>
<td></td>
<td>Dry towels/clothes</td>
<td>Maximum temperature</td>
<td>No additional cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Option to hang towels/clothes in front of heating device</td>
<td>Design radiator heating</td>
</tr>
<tr>
<td><strong>Lighting</strong></td>
<td>Good vision</td>
<td>Provide comfortable ambient lighting</td>
<td>300-500 lux light</td>
</tr>
<tr>
<td></td>
<td>Extra vision when brushing hair, etc.</td>
<td>Provide adjustable additional lighting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control over lighting</td>
<td>Provide hardware or software light switch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Automatic light control</td>
<td>Light sensor</td>
</tr>
<tr>
<td><strong>Electric</strong></td>
<td>A working lighting system</td>
<td>Provide power to lighting</td>
<td>12V connection</td>
</tr>
<tr>
<td></td>
<td>Option to charge electric razor, etc.</td>
<td>Provide means to recharge appliances</td>
<td>2.5 mm² section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12V connection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5 mm² section</td>
</tr>
<tr>
<td><strong>Ventilation</strong></td>
<td><strong>Installation</strong></td>
<td><strong>Partitionability</strong></td>
<td><strong>Adaptability</strong></td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Removal of moist air</td>
<td>Drain 1.4 l air per sec</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Removal of smells</td>
<td>Drain 1.4 l air per sec</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Easy &amp; quick installation</td>
<td>Readjustable slopes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Easy removal</td>
<td>-Use demountable connectors for installations</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Readjustable slopes</td>
<td>Readjustable installation heights</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plug and play connections</td>
<td>Plug and play water connection (example Quickfit)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-Simple suspension systems for connecting the installations</td>
<td>Plug and play wastewater connection (example plugin sleeve)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Modularity</td>
<td>Implement a detachable connector for each installation between modules</td>
<td>Only required for water, wastewater, electricity and data systems</td>
<td>-</td>
</tr>
<tr>
<td>Change building automation</td>
<td>Offer a software interface.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Makes small changes to sanitary fixtures</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add possible washing machine/dryer</td>
<td>Reserve space for an extra power connection</td>
<td>Option for a 230V power connection on separate electric circuit</td>
<td>-</td>
</tr>
<tr>
<td>Add possible electric connection</td>
<td>Reserve space for extra power connection</td>
<td>Electric grid around the mirror on the sink panel</td>
<td>-</td>
</tr>
<tr>
<td>Add possible data system</td>
<td>Reserve space for a data line</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add possible mechanical supply ventilation</td>
<td>Reserve space for a wireless data transmitter</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add possible (shower) heat recovery</td>
<td>Reserve space for extra ventilation ducts</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add additional toilet</td>
<td>Implement expansion to water and wastewater system</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add additional shower</td>
<td>Implement expansion to water and wastewater system</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add additional sink</td>
<td>Implement expansion to water and wastewater system</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add possible care facility</td>
<td>Option to add support brackets</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Add possible care facility</td>
<td>Option to add shower seat</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Allow low temperature heating</td>
<td>-Large radiator</td>
<td>Copper, PB pipes</td>
<td>-</td>
</tr>
<tr>
<td>Allow hot water circulation line</td>
<td>-Suitable material for hot water pipes</td>
<td>Application of legionella regulations</td>
<td>-</td>
</tr>
<tr>
<td>Mount installations in any place</td>
<td>-Prevention against future legionella</td>
<td>Homogenize mounting brackets</td>
<td>-</td>
</tr>
<tr>
<td>Prevent bacterial growth in water pipes</td>
<td>-Separate hot and cold water pipes</td>
<td>Pipes should quickly cool to under 25°C</td>
<td>-</td>
</tr>
<tr>
<td>Prevent condensation</td>
<td>-Apply sufficient insulation on cold water pipes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Prevent electrical shock</td>
<td>-Ground 230V electrics</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Prevent short circuit</td>
<td>-Ground metal components</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Save on electricity</td>
<td>-Apply a circuit breaker</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maintain heat</td>
<td>-Automatic light turn off</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-Insulation hot water pipes</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Appendix B: Specific Interface Solutions

### Mounting order

The main question for the mounting order is if there needs to be an additional connection step after the panel has been placed. If that is the case, there needs to be an installation panel to make the final connection.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Two stage mounting</td>
<td><img src="image1.png" alt="Image" /></td>
<td>An installation panel allows for additional flexibility in the future.</td>
<td>An installation panel is required to make the final connection.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Single stage mounting</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Installation is likely to be faster, and requires fewer components.</td>
<td>Connections have to be made 'in the dark'.</td>
</tr>
</tbody>
</table>

### Frame connection with bathroom

Every bathroom is different. The connection of prefab (or at least predetermined) installations to the building installations is therefore not the same in every case.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lean frame</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Remains close to the initial idea</td>
<td>Less protection versus lateral movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solves some overlapping problems</td>
<td></td>
</tr>
<tr>
<td>2. Flexible frame</td>
<td><img src="image4.png" alt="Image" /></td>
<td>The brackets can be located at the location of the force</td>
<td>Less protection versus lateral movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solves all overlapping problems</td>
<td></td>
</tr>
</tbody>
</table>

### Bathroom fixture installation

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet support</td>
<td><img src="image5.png" alt="Image" /></td>
<td>Guaranteed loadbearing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alleviation of the frame.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integrated toilet basin.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proven system.</td>
<td></td>
</tr>
<tr>
<td>Wall plate</td>
<td><img src="image6.png" alt="Image" /></td>
<td>No additional support required.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can be readjusted to some extent.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proven system.</td>
<td></td>
</tr>
<tr>
<td>1. Fixed rods</td>
<td><img src="image7.png" alt="Image" /></td>
<td></td>
<td>Limited in choice of sink.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Wall plate

Suitable for most sinks. A slot in the panel is required, which can be easily waterproofed by the wall plate. A wall plate is mounted at the back of the panel, specific for the required sink. Might allow for some variation in height. Changing sinks can require panel detachment.

3. Moveable rods

Suitable for most sinks. A slot in the panel is required. Two threaded rods that can laterally slide are mounted on the back of the panel.

### Location of pipes

The location of the pipes is mainly based on the way to prevent the growth of legionella bacteria. Separation of the hot and cold water plumbing is an option to reduce measures to prevent the growth of legionella. Installation has to be done at two locations. Optimizes pipe length. Measures to prevent the growth of legionella have to be taken.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bottom pipe</td>
<td><img src="image1.png" alt="Image" /></td>
<td>All the plumbing is located conveniently in one area. Synergizes with <strong>Two stage mounting</strong>.</td>
<td>Measures to prevent the growth of legionella have to be taken.</td>
</tr>
<tr>
<td>2. Top pipe</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Prevents all issues with the growth of legionella. Synergizes with <strong>Single stage mounting</strong>.</td>
<td>Installation has to be done at two locations.</td>
</tr>
<tr>
<td>3. Middle pipe</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Optimizes pipe length. Synergizes with <strong>Two stage mounting</strong>.</td>
<td>Measures to prevent the growth of legionella have to be taken.</td>
</tr>
</tbody>
</table>

### Location of major connection point for (dis)assembly purposes

The choice of connection point is one that logically results from other choices. As such it is only a descriptive choice, not to be made first.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bottom pipe connection</td>
<td><img src="image4.png" alt="Image" /></td>
<td>The connection can be made from the bottom panel. Synergizes with <strong>Two stage mounting</strong>.</td>
<td></td>
</tr>
<tr>
<td>2. Fixture pipe connection</td>
<td><img src="image5.png" alt="Image" /></td>
<td>No bottom panel is required. Synergizes with <strong>Single stage mounting</strong>.</td>
<td>Additional measures have to be taken to ensure the connection can be accessed.</td>
</tr>
<tr>
<td>3. Flexible connection</td>
<td><img src="image6.png" alt="Image" /></td>
<td>Can be useful combined with a (physically) flexible panel mounting, where the pipe has to be displaced slightly. Requires an additional connection.</td>
<td>A connection point at the side offers additional accessibility.</td>
</tr>
</tbody>
</table>
### Attachment to the loadbearing systems
The two options below are both satisfactory.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Installation rails</td>
<td><img src="image" alt="Image" /></td>
<td>Can be readjusted (for example in height to create a slope)</td>
<td>Can be disassembled.</td>
</tr>
<tr>
<td>The plumbing is suspended from an installation rails with rings.</td>
<td><img src="image" alt="Image" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Snap</td>
<td><img src="image" alt="Image" /></td>
<td>Quick to assemble</td>
<td>Can be disassembled.</td>
</tr>
<tr>
<td>The plumbing can be snapped into place.</td>
<td><img src="image" alt="Image" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Building connection
Every bathroom is different. A flexible system is required to account for uncertainty in the location of the building installations.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic solution</td>
<td><img src="image" alt="Image" /></td>
<td>A final flexible part connects to both the building installation and the IDF installation.</td>
<td>This method is not transferrable to other systems (non-flexible)</td>
</tr>
<tr>
<td>A final flexible part connects to both the building installation and the IDF installation.</td>
<td><img src="image" alt="Image" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Panel penetration
Because of the precondition of the mounting of the panel, it is not obvious how the plumbing can penetrate the panel.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Circumvention</td>
<td><img src="image" alt="Image" /></td>
<td>The pipe is rerouted so it does not interfere with the panel.</td>
<td>Does not solve the hole problem (only the movement). Obstacles for cleaning and hygiene.</td>
</tr>
<tr>
<td>The pipe is rerouted so it does not interfere with the panel.</td>
<td><img src="image" alt="Image" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Slot</td>
<td><img src="image" alt="Image" /></td>
<td>The panel has a slot instead of a hole to allow vertical movement in the panel during installation.</td>
<td>Requires a plug for a waterproof finish. Requires little modifications.</td>
</tr>
<tr>
<td>The panel has a slot instead of a hole to allow vertical movement in the panel during installation.</td>
<td><img src="image" alt="Image" /></td>
<td>Synergizes with Single stage mounting.</td>
<td>Might cause unattractive aesthetics.</td>
</tr>
<tr>
<td>3. Mounting direction</td>
<td><img src="image" alt="Image" /></td>
<td>The direction of the installation of the panel is changed.</td>
<td>Requires a new suspension system. Changes the whole concept.</td>
</tr>
<tr>
<td>The direction of the installation of the panel is changed.</td>
<td><img src="image" alt="Image" /></td>
<td>Synergizes with Single stage mounting.</td>
<td></td>
</tr>
<tr>
<td>4. Post installation</td>
<td><img src="image" alt="Image" /></td>
<td>The connection with the fixtures is done behind the panel.</td>
<td>Synergizes with Single stage mounting. Additional measures are required to prevent the pipe from bending. The connection cannot be verified for leakage. Difficult to remove panel.</td>
</tr>
<tr>
<td>The connection with the fixtures is done behind the panel.</td>
<td><img src="image" alt="Image" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Integration</td>
<td><img src="image" alt="Image" /></td>
<td>The pipe is mounted during prefabrication on the panel.</td>
<td>A large part of the system can be prefabricated.</td>
</tr>
<tr>
<td>The pipe is mounted during prefabrication on the panel.</td>
<td><img src="image" alt="Image" /></td>
<td></td>
<td>Synergizes with Two stage mounting.</td>
</tr>
</tbody>
</table>
6. Telescoping pipes

The pipe has a telescoping section.

Synergizes with Single stage mounting.

Telescoping pipes may not be reliable.

7. Flexible pipes

The pipe is flexible in such a way that it can be pushed backwards by the panel.

Synergizes with Single stage mounting.

Requires a system to flex the pipe back.

Flexible water connections

The connection type depends on the pipe material that is used. The specific connections here are connections that have the ability to be disassembled. Rigid pipes may not be practical.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A compression fitting</td>
<td>![Image]</td>
<td>Can be disassembled.</td>
<td></td>
</tr>
<tr>
<td>The connection is made by tightening the nut. A deformation in the inner ring (olive) creates a pressure between the pipe and an O-ring.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. A crimp fitting</td>
<td>![Image]</td>
<td>Requires crimping tools.</td>
<td></td>
</tr>
<tr>
<td>The connection is made by mechanically deforming the end of the pipe, or by compressing a crimp ring around the fitting.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. A speedfit</td>
<td>![Image]</td>
<td>Can be disassembled.</td>
<td>Frequent disassembly damages pipe.</td>
</tr>
<tr>
<td>The connection is made by inserting a pipe into the fitting. Slightly pulling the pipe back locks it into place.</td>
<td>Quick to assemble.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pipe material

The pipe material is a final choice. For most applications a suitable pipe can be found. Pipe material determines if a pipe is suitable for the transportation of hot water, and if a pipe is flexible. For the transportation of heating water, pipes with high pressure resistance are needed.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Copper (pure, red)</td>
<td>Suitable for hot water.</td>
<td>Installation takes relatively long.</td>
</tr>
<tr>
<td>A rigid pipe.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Wicu</td>
<td>Suitable for hot water.</td>
<td>Flexible tube requires pipe inserts for fittings.</td>
</tr>
<tr>
<td>A flexible copper pipe, encased in a foam sleeve.</td>
<td>Flexible.</td>
<td></td>
</tr>
<tr>
<td>Or a barrier version. The cross links increase pressure resistance.</td>
<td></td>
<td>Flexible tube requires pipe inserts for fittings</td>
</tr>
<tr>
<td>4. PB (poly-butylene)</td>
<td>Suitable for hot water.</td>
<td>Flexible tube requires pipe inserts for fittings.</td>
</tr>
<tr>
<td>Or a barrier version. PB has a higher melting point than regular PE.</td>
<td>Flexible.</td>
<td></td>
</tr>
<tr>
<td>Does not use precious copper.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Building connection

It is assumed that in one of the corners of the bathroom, there is a drainage pipe. The IDF system will be connected to this pipe. This might involve cutting a hole in the ground.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ball coupling</td>
<td>![Image]</td>
<td>The ball shape guides the drainage flow.</td>
<td>Requires cutting a hole to make the initial connection.</td>
</tr>
<tr>
<td>The sides can be connected to the IDF system.</td>
<td>Expansion possibility on top.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Plumbing connections

<table>
<thead>
<tr>
<th>Solution</th>
<th>Image</th>
<th>Advantages/synergies</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flexible fitting</td>
<td><img src="image1.png" alt="Image" /></td>
<td>The flexible material accounts for some uncertainty in slopes.</td>
<td>Requires crimping tool.</td>
</tr>
<tr>
<td>2. Plug socket</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Flexibility might not be required.</td>
<td></td>
</tr>
</tbody>
</table>