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Creating a New Perspective by Integrating Frames Through Design

An Exploratory Research into the What, Why, and How of Integrated Design

J.L. Visser

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Summary

Although many systems seem to perform well within their disciplinary boundaries when measured along their disciplinary performance indicators, the integration with other systems can be problematic. This integration with other systems is necessary to deal with challenges that reach beyond disciplinary boundaries. Especially in the civil infrastructure domain, the planning and construction of for example airports, seaports, roads, housing, and energy landscapes seem to come with great opposition. In addition to the civil infrastructure domain, also other domains show integration issues, appearing in problems of for example plastic waste, the decrease of available fresh water, and the problematic amount of emitted greenhouse gasses in cattle farming and air transport. Even when there is a desire to make a transition towards sustainable energy sources to decrease the amount of emitted greenhouse gasses, the responsible energy systems such as windmills and solar panel fields are not welcomed warmly in the natural and cultural landscape. It seems that many designs come with issues of integration when looking beyond the border of their own disciplinary frame. Solutions are required for challenges of climate adaptation, smart mobility, circularity, affordable housing, energy transition, and creation or remain of livable and green environments. These challenges go beyond institutional boundaries, space, and budgets. Therefore, the design and development of ways to integrate systems to solve issues of integration and to cope with these interrelated challenges is urgent and winning on interest. A shift from a 'distribution challenge' towards a 'design challenge' is essential to incorporate value for all stakeholders. Especially in the context of the growth of the world population, expansion and densification of urban areas, and in particular in densely populated and planned countries such as The Netherlands, integrated design should be a main priority.

'Integrated design' is in practice and design sciences literature a frequently used term. However, a common ground in definition and methodology is missing. Again, different design communities and disciplines use terminology and methodology within their own disciplinary frames. This causes misunderstanding in discussion and development between different disciplines and will not solve issues of integration. Therefore, the main research question of this dissertation is:

> *'How can integrated design be translated into a framework for semantic, methodological, and practical application?'*

The aim of this research is to develop a framework for integrated design in order to form a platform for semantic, methodological, and practical discussion and development. The platform can be used to bring different involved stakeholders and disciplines together. This dissertation presents an exploratory research that, in brief, forms an answer with respect to the 'what', 'why', and 'how' of integrated design.

Regarding the 'what' of integrated design can be said that in this dissertation integrated design is defined as the 'framing of the compatibility of multiple artifact frames'. In elaboration on this definition, first of all can be said that an 'artifact frame' is defined as the combination of the aspired value, which is heuristic, and the working principle of the system. In combination with the actual artifact, the working principle of this artifact is the way a system can lead to the aspired value. For example, the working principle of a dune body is the way flood risk reduction is aspired. The dune is the actual artifact in this context. With respect to the working principle, research can be done and designs can be made. In addition, a working principle can also fail or not be designed in a suitable way when the aspired value is not obtained.

A second term in the definition of integrated design is 'compatibility'. The compatibility is about the relation between multiple artifact frames. This can for example refer to the compatibility of the artifact frame of the dune and the artifact frame of the morphological development of the coastline, and related ecosystem quality. Five levels of compatibility refer to five types of the integration of different artifact frames, ranging from mutually incompatible forms of optimum aspired value on compatibility level 1, to multiple forms of optimum aspired value that can be obtained simultaneously through a certain working principle on compatibility level 5. As an example, the Sand Motor in front of the coast of Kijkduin shows the interrelated designs of these different artifact frames in correspondence to compatibility level 5. Flood risk reduction and ecosystem quality are for the Sand Motor designed in such a way that both forms of the optimum aspired value can be obtained simultaneously. Although nature cannot be defined as an artifact in itself, it can be part of planned development, which refers to an artifact frame for development.

Last term that is explained in the definition of integrated design is 'framing'. Framing refers to a 'frame' or 'lens', which can be defined from the perspective of the beholder, and from the perspective of the designer. The designer frames the relation between the stakeholders and a particular artifact. Especially the awareness about the layered structure of constraints that construct a frame is essential. The layered structure of constraints, differentiated in 'intrinsic', 'imposed', and 'self-imposed' constraints shows that the design space can be partly subordinate to design. This gives opportunities to frame the design space and therewith the compatibility of multiple artifact frames.

After understanding the 'what' of integrated design, the 'why' is at stake. Integrated design is first of all not an 'end' in itself, but is a 'means' in relation to a certain 'end'. The conceptual approach as presented in this dissertation shows the relation between integrated design, compatibility level 5, dissolution, and abundance. Briefly, the conceptual approach shows that when different artifact frames can be framed in such a way that different forms of aspired value can be obtained simultaneously, issues of integration dissolve, and a state of abundance with respect to the relation between different forms of aspired value can be created. The 'distribution challenge' is then translated into a 'design challenge'.

After the 'what' and the 'why', the 'how' refers to the research into the methodological component of the framework for integrated design. As part of the methodological investigation of design at different faculties of Delft University of Technology, the differences in interpretations of integrated design are discussed along a spectrum of abduction, ranging from 'defined abduction' to 'frame abduction'. Abduction refers to the hypothetical reasoning in design and corresponds with its heuristic character. With integrated design defined as the 'framing of the compatibility of multiple artifact frames', 'defined abduction' implies integrated design as the 'framing of the compatibility of multiple defined artifact frames'. For 'frame abduction', the definition of the artifact frame is part of the design itself. This means that the 'framing of the compatibility of multiple artifact frames' is subordinate to design for 'frame abduction'. The different relations between the methodological structures and the definition of the design space for integrated design will result in different perspectives on integrated design. When artifact frames are predefined, integrated design will focus on the integration of the actual artifacts, which can be marked as a technical interpretation of integrated design. When the definition of the artifact frames is part of the design itself, integrated artifact frames can lead to new typologies of artifacts, which can be marked as a more conceptual interpretation of integrated design. To what extent the artifact frames are predefined or part of the design itself, frames the definition of the design space for integrated design, and therewith also the interpretation of integrated design.

'Frame abduction' is especially relevant for (re)framing the compatibility of multiple artifact frames. A meta-method incorporates this mode of reasoning in design steps that are obtained from the common ground in different integrated design approaches. From the common ground, two main design phases, with in total four design steps, are differentiated that construct the meta-method for integrated design. These main design phases with corresponding design steps are formulated as:

Frame awareness:
1) Identifying different artifact frames
2) Identifying a typology of constraints

Designer framing:
3) Translating aspired value into values
4) Defining common working principles and forms of aspired value

The meta-method is not intended to replace currently used methodological structures, but can be applied in parallel to support solving issues of integration. The meta-method adds a methodological component to the act of design in the conceptual approach and forms a common ground for methodological discussion and development.

At last, in addition to the theoretical framework, the main findings from integrated design in practice add a complementary perspective to the framework for integrated design. Three cases are researched along three topics, which are formulated as 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. With respect to the three different cases holds that they are all related to the civil infrastructure domain, are related to water challenges, and are located in The Netherlands. The three researched cases are Coast Katwijk, Benthemplein, and Biomakery Strijp-S. Although the researched cases are related to different types of water challenges, they show similarities within the mentioned topics. A first finding was that integrated design can be applied as a means for strategic development. Sometimes, a stakeholder lacks the power, properties, resources, or space to apply a mono-functional system within the boundaries of their institutional responsibilities. Integration of functions through common working principles with other systems can then be applied strategically. In addition, how the design is integrated is dependent of the functional hierarchy, lifecycles, scale level of motivation for integration, and institutional responsibilities. Exemplary in this context are the separated structures of the 'dike in dune' and parking garage under the dune body in case Coast Katwijk. While the structures of the 'dike in dune' and the parking garage are separated, they look spatially one on level of the dune body. The scale level of the dune body corresponds with the scale level of the motivation for integration. The motivation for integration determines the type of integration on different scale levels.

To create an integrated case, the momentum is key, because different stakeholders can have different interests and resources at different moments in time. Thereby, the framing of the integrated case in relation to policies and budgets is key to create a feasible case. Integrated design frequently requires that organizations have to act at the edges of their responsibilities and expertise, and in some cases even adjust their policies and governance structures. From that perspective, personal commitment and courage of ambitious people with the experience to know how to act in such an integrated design process is key as well. The findings from integrated design in practice form the elements that shape the window of opportunity for integrated design.

The building blocks that refer to the 'what', 'why', and 'how' of integrated design construct together the framework for integrated design. This framework can be applied as a platform for semantic, methodological, and practical discussion and development. T-shaped professionals in integrated design should be trained in applying the framework to become specialists in the field of integrated design.

Samenvatting

Hoewel veel systemen aan de hand van hun prestatie indicatoren goed lijken te presteren binnen hun disciplinaire grenzen kan de integratie met andere systemen problematisch zijn. Deze integratie met andere systemen is noodzakelijk om opgaven die over disciplinaire grenzen reiken het hoofd te bieden. Vooral in het domein van de civiele infrastructuur lijkt de planning en bouw van bijvoorbeeld luchthavens, zeehavens, wegen, woningen en energielandschappen gepaard te gaan met grote oppositie. Naast het civiel infrastructurele domein vertonen ook andere domeinen integratieproblemen, die zich voordoen in problemen met bijvoorbeeld plastic afval, de afname van de beschikbaarheid van zoet water, en de problematische hoeveelheid uitgestoten broeikasgassen in de veehouderij en luchtvaart. Zelfs de transitie naar duurzame energiebronnen, in de vorm van windmolens en velden met zonnepanelen, om de hoeveelheid uitgestoten broeikasgassen te verminderen, wordt niet hartelijk verwelkomd in het natuurlijke en culturele landschap. Het lijkt of veel ontwerpen gepaard gaan met integratieproblemen als er verder gekeken wordt dan het eigen disciplinaire kader. Oplossingen worden gevraagd voor uitdagingen zoals klimaatadaptatie, slimme mobiliteit, circulariteit, betaalbare huisvesting, energietransitie, en het creëren of behouden van een leefbare en groene omgeving. Deze uitdagingen gaan verder dan institutionele grenzen, ruimte, en budgetten. Om die reden zijn het ontwerp en de ontwikkeling van manieren om systemen zodanig te integreren dat ze integratieproblemen oplossen en deze onderling samenhangende uitdagingen het hoofd bieden urgent, en winnen aan belangstelling. De verschuiving van een 'verdeelvraagstuk' naar een 'ontwerpvraagstuk' is essentieel om waarde te kunnen incorporeren voor alle stakeholders. Vooral in de context van een groeiende wereldbevolking, uitbreiding en verdichting van stedelijke gebieden, en in het bijzonder in dichtbevolkte en geplande landen zoals Nederland, zou geïntegreerd ontwerpen een hoofdprioriteit moeten zijn.

'Geïntegreerd ontwerpen' is een term die regelmatig wordt gebruikt in de praktijk en in literatuur in de ontwerpwetenschappen. Een gemeenschappelijke basis in definitie en methodologie ontbreekt echter. Hier geldt ook weer dat verschillende ontwerpgroepen en disciplines elk hun eigen terminologie en methodologie gebruiken binnen hun eigen disciplinaire kaders. Dit veroorzaakt misverstanden in discussie en ontwikkeling tussen verschillende disciplines en draagt niet bij aan het oplossen van integratieproblemen. De hoofdvraag van dit onderzoek luidt daarom als volgt:

> *'Hoe kan geïntegreerd ontwerpen worden vertaald in een raamwerk voor semantische, methodologische, en praktische toepassing?'*

Het doel van dit onderzoek is om een raamwerk te ontwikkelen voor geïntegreerd ontwerpen, dat een platform vormt voor semantische, methodologische, en praktische discussie en ontwikkeling. Het platform kan gebruikt worden om verschillende stakeholders en disciplines samen te brengen. Dit proefschrift presenteert een

exploratief onderzoek dat in het kort een antwoord vormt met betrekking tot de 'wat', 'waarom', en 'hoe' van geïntegreerd ontwerpen.

Bij de 'wat' van geïntegreerd ontwerpen wordt geïntegreerd ontwerpen in dit proefschrift gedefinieerd als de 'framing van de compatibiliteit van meerdere artefact frames'. Hierbij wordt een 'artefact frame' gedefinieerd als de combinatie van de beoogde of nastreefde waarde, die heuristisch is, en het werkingsprincipe van het systeem. De combinatie van het artefact en het werkingsprincipe van dit artefact kan leiden tot de beoogde waarde. Een werkingsprincipe van een duinlichaam is de manier waarop een vermindering van het overstromingsrisico wordt nagestreefd en het duin is het eigenlijke artefact. Met betrekking tot het werkingsprincipe kan onderzoek worden gedaan en kunnen ontwerpen worden gemaakt. Daarnaast kan een werkingsprincipe ook falen of niet ontworpen worden op een geschikte manier als de beoogde waarde niet wordt verkregen.

Een tweede term in de definitie van geïntegreerd ontwerpen is 'compatibiliteit'. De compatibiliteit gaat over de relatie tussen meerdere artefact frames. Dit kan bijvoorbeeld gaan over de compatibiliteit van het artefact frame van het duin en het artefact frame van de morfologische ontwikkeling van de kustlijn, en de hieraan gerelateerde ecosysteem kwaliteit. In deze dissertatie worden vijf niveaus van compatibiliteit onderscheiden, die verwijzen naar vijf typen integratie van verschillende artefact frames, variërend van onderling onverenigbare vormen van optimale nagestreefde waarde op compatibiliteitsniveau 1, tot meerdere vormen van optimale nagestreefde waarde die gelijktijdig kunnen worden verkregen via een bepaalde werkingsprincipe op compatibiliteitsniveau 5. Als voorbeeld toont de Zandmotor voor de kust van Kijkduin de onderling samenhangende ontwerpen van deze verschillende artefact frames in overeenstemming met compatibiliteitsniveau 5. De vermindering van het overstromingsrisico en verhoging van de kwaliteit van het ecosysteem zijn voor de Zandmotor ontworpen op zo'n manier dat beide vormen van de optimale nagestreefde waarde tegelijkertijd kunnen worden verkregen. Hoewel de natuur op zichzelf niet kan worden gedefinieerd als een artefact kan het onderdeel zijn van een geplande ontwikkeling die refereert aan een artefact frame voor ontwikkeling.

De laatste term die wordt toegelicht in de definitie van geïntegreerd ontwerpen is 'framing'. Framing refereert aan een frame of lens, die kan worden gedefinieerd vanuit het perspectief van de toeschouwer en vanuit het perspectief van de ontwerper. De ontwerper geeft vorm aan de relatie tussen de stakeholders en een bepaald artefact. Vooral het bewustzijn over de gelaagde structuur van beperkingen die een frame vormen is essentieel. De gelaagde structuur van beperkingen, gedifferentieerd in 'intrinsieke', 'opgelegde', en 'zelfopgelegde' beperkingen, laat zien dat de ontwerpruimte gedeeltelijk ondergeschikt kan zijn aan het ontwerp. Dit biedt mogelijkheden om de ontwerpruimte te framen en daarmee de compatibiliteit van meerdere artefact frames.

Na inzicht in het 'wat' van geïntegreerd ontwerpen, is het 'waarom' van belang. Geïntegreerd ontwerpen is in de eerste plaats geen doel op zich, maar is een middel in relatie tot een bepaald doel. De conceptuele aanpak zoals gepresenteerd in dit proefschrift toont de relatie tussen geïntegreerd ontwerpen, compatibiliteitsniveau 5, oplossing, en overvloed. In het kort laat de conceptuele benadering zien dat wanneer verschillende artefact frames kunnen worden gevormd op een zodanige manier dat verschillende vormen van nagestreefde waarde tegelijkertijd kunnen worden verkregen, integratieproblemen kunnen worden opgelost en een staat van overvloed met betrekking tot deze onderlinge relatie kan worden verkregen. Het 'verdeelvraagstuk' is dan vertaald in een 'ontwerpvraagstuk'.

Na het 'wat' en het 'waarom', refereert het 'hoe' aan het onderzoek naar de methodologische component van het raamwerk voor geïntegreerd ontwerpen. Als onderdeel van het methodologische onderzoek naar ontwerpen aan verschillende faculteiten van de Technische Universiteit Delft, zijn de verschillende in interpretaties van geïntegreerd ontwerpen besproken langs een spectrum van abductie, variërend van 'gedefinieerde abductie' tot 'frame abductie'. Met geïntegreerd ontwerpen gedefinieerd als de 'framing van de compatibiliteit van meerdere artefact frames', 'gedefinieerde abductie' impliceert geïntegreerd ontwerpen als de 'framing van de compatibiliteit van meerdere gedefinieerde artefact frames'. Voor 'frame abductie' maakt de definitie van het artefact frame deel uit van het ontwerp zelf. Dit betekent dat de 'framing van de compatibiliteit van meerdere artefact frames' ondergeschikt is aan ontwerp in het geval van 'frame abductie'. De verschillende relaties tussen de methodologische structuren en de definitie van de ontwerpruimte voor geïntegreerd ontwerpen zullen leiden tot verschillende perspectieven op geïntegreerd ontwerpen. Als artefact frames vooraf zijn gedefinieerd zal geïntegreerd ontwerpen focussen op de integratie van artefacten, welke kan worden getypeerd als een technische interpretatie van geïntegreerd ontwerpen. Wanneer de definitie van de artefact frames deel uitmaakt van het ontwerp zelf, kunnen geïntegreerde artefact frames leiden tot nieuwe typologieën van artefacten, welke kunnen getypeerd worden als een meer conceptuele interpretatie van geïntegreerd ontwerpen. In hoeverre de artefact frames vooraf zijn gedefinieerd of deel uitmaken van het ontwerp zelf, vormt de definitie van de ontwerpruimte voor geïntegreerd ontwerpen, en daarmee ook de interpretatie van geïntegreerd ontwerpen.

'Frame abductie' is vooral relevant voor (re)framing van de compatibiliteit van meerdere artefact frames. Een meta-methode neemt deze manier van redeneren op in ontwerpstappen die worden verkregen uit de gemeenschappelijke grond in verschillende geïntegreerde ontwerpbenaderingen.

Vanuit de gemeenschappelijke grond worden twee hoofdontwerpfasen met in totaal vier ontwerpstappen onderscheiden die de meta-methode voor geïntegreerd ontwerpen vormen. De hoofdontwerpfasen met ontwerpstappen zijn geformuleerd als:

Framebewustzijn:

1) Identificatie van verschillende artefact frames
2) Identificatie van een typologie van voorwaarden

Ontwerper framing:

3) Nagestreefde vormen van waarde vertalen in waarden
4) Definiëren van gemeenschappelijke werkingsprincipes en vormen van nagestreefde waarde

De meta-methode is niet bedoeld om huidige gebruikte methodologische structuren te vervangen, maar kan parallel worden toegepast om het oplossen van integratieproblemen te ondersteunen. De meta-methode voegt een methodologische component toe aan de ontwerpactiviteit in de conceptuele aanpak en vormt een gemeenschappelijke grond voor methodologische discussie en ontwikkeling.

Ten slotte voegen de belangrijkste bevindingen van geïntegreerd ontwerpen in de praktijk, naast het theoretisch kader, een aanvullend en complementair perspectief toe aan het kader voor geïntegreerd ontwerpen. Drie casussen zijn onderzocht op drie topics, die zijn geformuleerd als 'a) motivatie voor integratie', 'b) ontwerpaspecten in relatie tot integratie', en 'c) voorwaarden voor het geïntegreerde ontwerpproces'. Met betrekking tot de drie verschillende casussen geldt dat ze allemaal zijn gerelateerd aan het civiele infrastructurele domein, gerelateerd zijn aan wateropgaven, en zich in Nederland bevinden. De drie casussen zijn Kustwerk Katwijk, Benthemplein, en Biomakerij Strijp-S. Hoewel de onderzochte casussen verband houden met verschillende soorten wateropgaven vertonen ze overeenkomsten binnen de genoemde topics. Een eerste bevinding was dat geïntegreerd ontwerpen kan worden toegepast als een middel voor strategische ontwikkeling. Soms ontbreekt het een stakeholder aan de macht, eigendommen, middelen, of ruimte om een monofunctioneel systeem toe te passen binnen de grenzen van de eigen institutionele verantwoordelijkheden. Integratie van functies door gemeenschappelijke werkingsprincipes met andere systemen kan vervolgens strategisch worden toegepast. Daarnaast is de manier waarop het ontwerp is geïntegreerd afhankelijk van de functionele hiërarchie, levenscycli, schaalniveau van de motivatie voor integratie, en institutionele verantwoordelijkheden. Exemplarisch in deze context zijn de gescheiden constructies van de 'dijk in duin' en de parkeergarage onder het duinlichaam in de casus Kustwerk Katwijk. Terwijl de constructies van de 'dijk in duin' en de parkeergarage zijn gescheiden lijken ze ruimtelijk één op het schaalniveau van het duinlichaam. Het schaalniveau van het duinlichaam correspondeert met het schaalniveau van de motivatie voor integratie. De motivatie voor integratie bepaalt het type integratie op verschillende schaalniveaus.

Om een geïntegreerde casus te creëren is het momentum cruciaal, omdat verschillende stakeholders op verschillende momenten verschillende belangen en middelen kunnen hebben. Daarbij is de framing van de geïntegreerde casus in relatie tot beleid en budgets van cruciaal belang om een haalbare casus te creëren. Geïntegreerd ontwerpen vereist vaak dat organisaties moeten acteren op de grenzen van hun eigen verantwoordelijkheden en expertise, en in sommige gevallen zelfs beleid en bestuursstructuren aanpassen. Vanuit dat perspectief is ook de persoonlijke toewijding en lef van ambitieuze mensen met de ervaring hoe te handelen in zulke geïntegreerde ontwerpprocessen van cruciaal belang. De bevindingen van geïntegreerd ontwerpen in de praktijk vormen de elementen die de ruimte voor geïntegreerd ontwerpen definiëren.

De bouwstenen die verwijzen naar het 'wat', 'waarom', en 'hoe' van geïntegreerd ontwerpen vormen samen het raamwerk voor geïntegreerd ontwerpen. Dit raamwerk kan worden toegepast als een platform voor semantische, methodologische, en praktische discussie en ontwikkeling. T-shaped professionals in geïntegreerd ontwerpen zouden moeten worden opgeleid in het toepassen van het raamwerk om specialisten te worden op het gebied van geïntegreerd ontwerpen.

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1 Introduction

1.1 Motivation for Research into Integrated Design

People have always been designers. From the first artifacts for hunting and shelters for protection, until today's designs of cars, airplanes, windmills, and cities. The modern examples of artifacts also show that the leverage of people increased through these human-designed systems over time. For example, nowadays an average car engine has a power with an equivalent of 120 horses. In the past, people could only dream of such a powerful tool. It can be said that human-designed systems have brought development and prosperity, or at least leverage, for those who can afford them and are able to use them. However, modern human-designed systems also have to be placed in the context of the exponential growth of the world population from the 18th century until now. Figure 1 shows the exponential growth of the world population graphically, with a growth of about 6 billion people from the start of the 20th century until now. With the growth of the world population, the sum of people's need for space, water, materials, energy, and food causes an increasing pressure on Earth's resources, animal habitats, atmospheric conditions and related weather patterns. Especially in developed countries, people's degenerative footprint is high. The access of people to human-designed systems to increase their leverage to their benefit then also seems to cause leverage at the cost of Earth's natural resources.

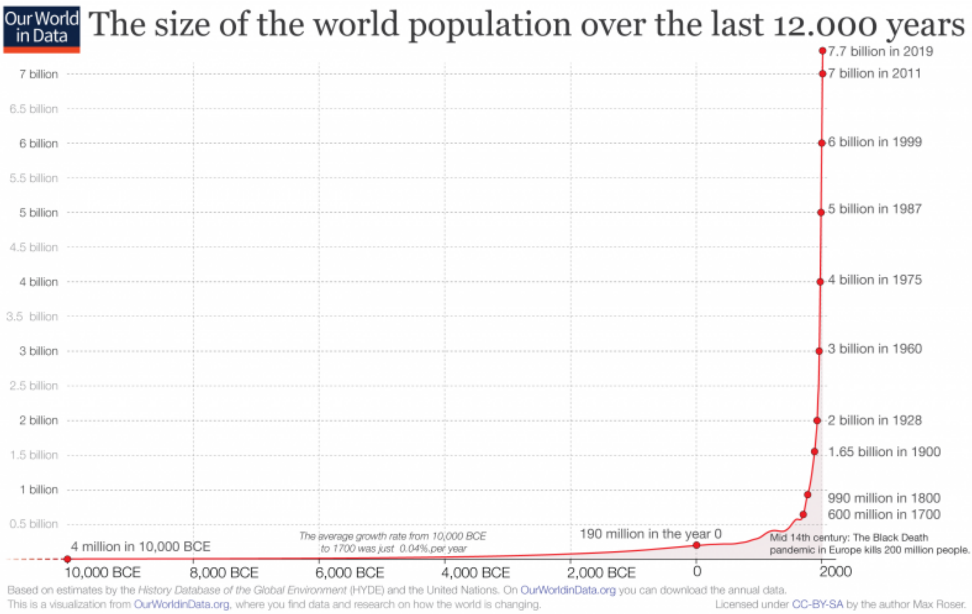


Figure 1 Exponential growth of the world population from the 18th century
Source: Roser et al. (2013)

The enormous impact of an increasing amount of people and related human-designed systems on their environment is nowadays even discussed as marking a separately defined era, the so-called 'Anthropocene' (Monastersky, 2015; Waters et al., 2016). Setting this time apart as a distinguished era that is defined by the human footprint also places perspectives on design in a new context. It raises the question on how design can actually facilitate the needs when a linear distribution of space and resources is not possible or desirable anymore. To illustrate this with an example, in 2014, 50 countries experienced fresh water stress or fresh water scarcity. This can be set in comparison to 30 countries in 1992, with a linear increase over the years. Of these countries, 41 percent of them were African and 25 percent Asian. While this situation is already alarming, fresh water security in combination with the expectation of high population growth numbers in these areas in the near future seems to increase pressure on the already hard situations these people live in (World Wildlife Fund, 2016). When multiple stakeholders claim the scarce space and resources, the distribution of the space and resources can become subordinate to power play between stakeholders, in which some or all of them have to do a concession or compromise. However, this is not desirable from an ethical point of view. Integration of interests through design will become necessary to cope up with the interrelated needs of a still growing world population, which becomes increasingly challenging.

The foregoing example points out a situation of scarcity that can appear in relation to a natural resource, in this case fresh water. However, a situation of scarcity can also appear in less critical conditions, but still in a context in which a linear distribution of space is not possible. For example, looking at large infrastructure projects, a lot of these projects are confronted with public opposition, especially in developed countries. The pressure on living space and quality of the living area in dense urban areas comes to light for projects that pushes hardest on these aspects. These projects do not only come with environmental pressure, but also with pressure of human activities on other human activities. The negative effects of mutual relations are in this context frequently related to the so-called Not-In-My-Backyard-Syndrome (NIMBY) (Kraft & Clary, 1991; Hertogh & Westerveld, 2010). NIMBY projects can be described as projects that are perceived as unpleasant or hazardous by people in their own neighborhood, while raising no objections to similar development elsewhere. Many modern infrastructure projects, like airports, train tracks, highways and energy plants, have to deal with sentiments of 'Not-In-My-Backyard' and their license-to-operate and license-to-grow are under pressure. Interestingly, even artifacts like modern windmills that provide a sustainable alternative for converting energy are confronted with severe opposition in many places. Although many people's opinion in relation to the transition towards sustainable energy alternatives is positive, Wolsink (2000) argues that the direct aesthetic impact of windmills outweighs the positive transition towards sustainable energy alternatives. The decision-making seems in this case to concentrate around the trade-off: sustainable energy with accepting undesirable landscape aesthetics and noise nuisance, or traditional polluting energy sources, but maintaining the landscape and a quiet environment. This seemingly necessary trade-off is not desirable from an ethical point of view (Van den Hoven et al., 2012). In addition, these trade-offs are also prone to power play between stakeholders with different interest and therewith a hierarchical differentiation between interests. This is neither desirable from an ethical point of view. However, the different interests remain confronted with each other, because of the lack of space to achieve them separately. The example of the conflicting relation between the desire for harvesting renewable wind energy on the one hand, and the negatively perceived impact of modern windmills on the other hand, illustrates the need to (re)design the relation between these aspects.

The examples in relation to the footprint of people's activities illustrate that incorporating different interests through design, without also incorporating trade-offs, is a challenge. The perceived positive impact with respect to a stakeholder's particular interest seems at the cost of another interest in many cases. In addition, the benefit of one aspect at the cost of another aspect seems to be so-called 'tightly coupled' (Weick, 1976). The interests that refer to different system aspects can be related to a single stakeholder or multiple stakeholders in design. Roland and Luanda (2013) call, in terms of capital, the gain of one aspect at the cost of another aspect the 'exchange of capital'. In their book 'Regenerative Enterprise', Roland and Luanda define eight forms of capital, namely 'social', 'material', 'financial', 'living', intellectual', 'experiential', 'spiritual', and 'cultural'. More forms of capital could be defined, but these eight forms of capital illustrate different possible frames or lenses, and refer to different interests of stakeholders. The degenerative relation between human-designed systems and the environment, as described in for example Tittensor et al. (2014) and the Word Wildlife Fund (2018), or the tension between human-designed systems and the quality of the living area, as described by Wolsink (2000) for the example of modern windmills, are characterized by the 'exchange of capital'.

The 'exchange of capital', as described by Roland and Luanda (2013), can also be translated into the 'exchange of value'. The 'exchange of value' implies that a particular form of value is obtained at the cost of another form of value. For example, obtaining more financial value at the cost of natural value. The term 'value' is used as a substitute for the term 'capital', because it covers a broader field of application. 'Value' is explicitly used in the singular form, because the term 'value' can have different meanings in different contexts. Used in the singular, 'value' can be defined as expressing the worth, importance or usefulness of something. This can also be the definition of 'value' in the plural form, but 'value' in the plural form can also be seen in relation to belief and social behavior (Fernandes, 2012). Therefore, the term 'forms of value' is used to distinguish multiple lenses in relation to value, such as financial value, social value, and ecological value.

In addition to an explicit exchange of value through trade-offs in tightly coupled systems, there can also be a lack of opportunities to incorporate value through design. The lack of opportunities to incorporate value can be less explicit than trade-offs in integrated design, but are also undesirable from a value point of view. An example that illustrates design choices in relation to the integration of 'opportunities to incorporate value' was given by Puts and Van der Heijden (2017a), who described the design of an outdoor sports field. By increasing the level of the sports field, the ground body under the field could also function as a water buffer in conditions of heavy rainfall. This water buffer would also alleviate the pressure on the drainage and sewerage system. In addition, the buffering capacity of the total system would become larger, which would also leave capacity in situations of climate change, with more heavy rainfall. This would possibly also lower maintenance cost of the sports field and drainage systems due to less pressure on the total system. Finally, with a sports field that could be played on for more days, more social activity takes place, which increases the social cohesion and livability of a neighborhood. While the sports field was maybe not associated with the water buffering capacity and climate adaption on beforehand, increasing the level of the sports field could create opportunities to gain other forms of value through a tightly coupled system design, as illustrated in Figure 2. It can be said that the plan to increase the level of the sports field shapes the 'window of opportunity' to incorporate additional forms of value. Kingdon (1995) presented the term 'window of opportunity' as shaped by a problem, policy, and politics stream. However, the term 'window of opportunity' will in this dissertation not exclusively be described in the context of the problem, policy, and politics stream, but described in the context of the elements that shape the window of opportunity for integrated design in the researched cases.

A second term that is relevant in this context is 'cascading effect'. The different forms of value, reasoned from the sports field, show an upward cascading effect of opportunities. The term cascading effect is in this dissertation used to describe the cascading relation between different forms of value, apart from the fact if the direction of the cascading effect is upward or downward.

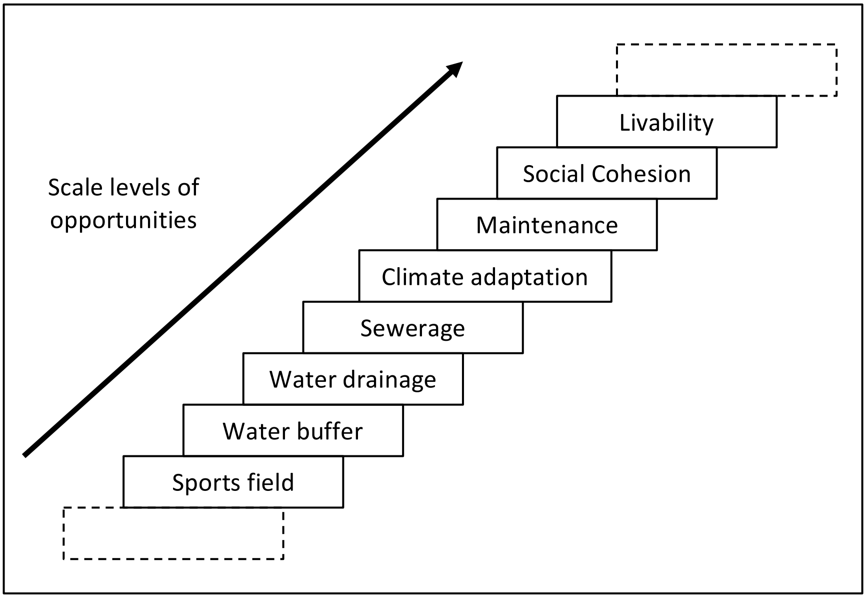


Figure 2 Opportunities to incorporate value for a sports field development
Source: Puts & Van der Heijden (2017b) (translated figure)

Earlier was already stated that by setting this time apart as a distinguished era that is defined by the human footprint, perspectives on design are placed in a new context as well. The different examples that were given illustrated this context and showed that a linear distribution of value by applying separately defined human-designed systems with their own use of space and resources is not always possible or desirable anymore. However, until now human-designed systems seem to be related to multiple issues in their relation to other systems and corresponding incorporation of forms of value (Jones, 1992). The term 'issue' is used in this context, because it can in this dissertation refer to problems, but can also refer to a lack of opportunities to incorporate value. Although a lack of opportunities to incorporate value would initially not be characterized as a problem, it needs to be addressed and taken care of. The term 'issue' is therefore referring to something that is pressing.

With a predicted increase of the world population from 7.5 billion people in 2017 up to 9.8 billion by 2050 (United Nations, 2017), issues of integration will rise and be subject to increasing societal pressure. However, in addition to the prediction of a 25 percent growth of the world population by 2050, The United Nations also declared that everyone has a right to nutritious food, clean water for drinking and sanitation, and adequate housing, as part of the 'Sustainability Development Goals' (United Nations, 2018). The increasing societal pressure to find solutions for issues of integration, in combination with the predicted growth of the world population, shows that current human-designed systems cannot fulfill the ambitions of the United Nations. Therefore the design and development of ways to integrate systems in terms of interests and value, in order to cope with these ambitions is urgent and should be a main priority.

The urgency of solving issues of integration is a challenge that is about the relation between for example different systems, elements, and disciplines. This challenge will also demand education that trains the professionals of the future to create solutions with respect to this challenge. Hertogh (2013) states that these professionals of the future should be characterized as T-shaped professionals, in which specialist disciplinary knowledge is added with generalist knowledge of the different involved disciplines. For such education programs and training the professionals of the future for cases of integrated design, first the 'what', 'why', and 'how', of integrated design are important. The framework as presented in this dissertation functions in that case as a platform for discussion about, and development of, the field of integrated design. The framework will contain the principle notes that can be defined from the exploratory research, and form the pinpoints that have to be taken into account when integrated design is at stake. Its function as a 'platform' is meant in the way that the terminology and methodology from this dissertation can be used to bring different involved stakeholders and disciplines together. Therewith, it also presents which aspects should be emphasized when training T-shaped professionals for cases of integrated design.

1.2 Problem Statement

Although there is a need for designing and developing ways to integrate systems in their context, there seems to be a lack of terminological and methodological common ground for defining and discussing integrated design. In addition, scientific literature neither provides a common ground for solving issues of integration from a theoretical point of view. In this context, this dissertation addresses the scientific gaps related to integrated design.

First of all, there is a scientific gap with respect to defining integrated design. A first investigation of scientific literature shows that 'integrated design' can be found more described in a certain context than explicitly defined. In addition, there seem to be multiple interpretations of integrated in a context of design. To discuss and develop integrated design, there is a need for a terminological common ground. When there is not a terminological common ground for integrated design, this may cause confusion and failure in the design process due to miscommunication and interpretation.

Subsequently, there is a second scientific gap between how integrated design can be defined and how integrated design can support solving issues of integration. When there is not a conceptual approach for solving issues of integration through design, the discussion about integrated design lacks direction for application.

In addition to a terminological common ground, there is neither a methodological common ground for integrated design. In this context, a third scientific gap can be stated with respect to the description of the relation between the methodological structure and the definition of the design space for the design of an artifact. Examples of explicit methodological structures are design methods and design process models. These methodological structures shape the definition of the design space. The design space is constructed by the problem space or opportunity space, and the interrelated solution space. If something can be defined as a problem or an opportunity is in many cases perception dependent. Nevertheless, both problem space and opportunity space refer in combination with the solution space to the definition of the design space. The 'problem space' is in this dissertation defined as 'the system of constraints that defines the boundaries for defining the problem'. In addition, the 'opportunity space' is in this dissertation defined as 'the system of constraints that defines the boundaries for defining the opportunity'. Finally, the 'solution space' is in this dissertation defined as 'the system of constraints that defines the boundaries for developing a solution'.

In addition, from a problem-solving perspective, Rittel and Webber (1973) also note the presence of so-called 'wicked problems'. 'Wicked problems' are 'ill-defined' problems, in contrast to 'well-defined' problems. When the problem space is ill-defined, the design space is also ill-defined. Churchman (1967) even makes a distinction in well-defined problems, ill-defined problems, and wicked problems. In Rowe's (1987) differentiation of problems, wicked problems are described as a separate type of very ill-defined problems. In this dissertation, wicked problems are assumed as a type of ill-defined problems and therefore only a differentiation is made in well-defined problems and ill-defined problems.

To develop a defined design space, Maher et al. (1996) describe the so-called 'co-evolution of the problem-solution pair', which refers to the process of defining the design space in the case of ill-defined problems. While Rittel and Webber (1973) and Maher et al. (1996) refer to the definition of the problem space in relation to the solution space, the same holds for the definition of the opportunity space in relation to the solution space. Both refer to the definition of the design space. The process towards the definition of the design space is methodologically structured. Therefore, understanding the relation between the methodological structure and the development of the design space for the design of an artifact is essential to understand the influence of the use of methodological structures, such as design methods and design process models.

The fourth scientific gap is related to the absence of a meta-method for integrated design. Design sciences do provide integrated design approaches for applications, such as 'Building with Nature' or 'Value-Sensitive Design', but do not provide a methodological common ground from which new integrated design methods and approaches can be developed for other applications. Without a meta-method, design methods and approaches have to be developed within every design field on its own, while a general method can support the discussion and development of integrated design methods and approaches for multiple applications.

Finally, there is a gap between seemingly integrated design projects in practice, and the description of the motivation for integration, the design aspects that determine how a design is integrated, and conditions for the integrated design process. A deeper understanding of design choices in practice is necessary to position the discussion of integrated design in a practical context.

This dissertation will focus on the defined scientific gaps along the defined research questions, which are presented in the following section 1.3.

1.3 Research Questions

The different research gaps together emphasize the need for a framework for integrated design. This framework is structured along three main parts, which are derived from the stated research gaps. The three main parts of the framework for integrated design are: 'Semantics Integrated Design', 'Methodology Integrated Design', and 'Integrated Design in Practice'. The main question of this research is in this context formulated as:

> *'How can integrated design be translated into a framework for semantic, methodological, and practical application?'*

The main question of this research is on its turn differentiated in 'research questions', and corresponding 'sub-questions'. The sub-questions should construct an answer to the research questions. An overview of the research questions and sub-questions is given in the scheme of Figure 3.

The problem statement in section 1.2 illustrated the scientific gaps that define the relevance for researching integrated design. First of all, there is a scientific gap with respect to defining integrated design. Research question 1 is related to this research gap. In sub-questions 1.1 and 1.2, the definitions for design and for integrated are researched in order to construct an answer on what integrated design is.

In addition to the question what integrated design is, a second scientific gap is stated between what integrated design is and how integrated design can support solving issues of integration. The question how integrated design can support solving issues of integration should result in a conceptual approach for solving issues of integration through design. Research question 2 is related to this research gap. Sub-question 2.1 is about what defines the design space for integrated design, while sub-question 2.2 focuses on how integrated design can determine the space to incorporate value. The issues of integration are about possibilities to incorporate of value. In this context, solving issues of integration is related to the incorporation of value through design.

The research results of research question 1 and research question 2 construct in Part I the 'Semantics Integrated Design'.

Section 1.2 also illustrated a scientific gap with respect to design methodology. The question what the relation is between the methodological structure and the definition of the design space for integrated design is defined in research question 3. In order to develop a meta-method for integrated design in the sequential chapter 4, the understanding of this relation is essential. Therefore, first of all a literature study is conducted with respect to the development of methodological structures over time, which is related to sub-question 3.1. This is done to understand the context of the currently used methodological structures. After that, different faculties of Delft University of Technology are investigated on their methodological structures for the design of an artifact for sub-question 3.2. This will give an overview the differences and commonalities between methodological structures of different faculties. Sub-question 3.1 and 3.2 construct an answer for research question 3.

The question how integrated design can be structured in a meta-method is defined in research question 4. The key-elements for a method are obtained from already existing integrated design methods for sub-question 4.1. Sub-question 4.2 focuses on its turn on the question how these key elements can be translated into a design process model for integrated design. The meta-method will be developed from sub-question 4.1 and 4.2 through an inductive approach.

The research results of research question 3 and research question 4 form the 'Methodology Integrated Design' in Part II. Together, the 'Semantics Integrated Design' in Part I and the 'Methodology Integrated Design' in Part II form the theoretical framework.

Part III is related to research question 5, and is about the description of the main findings from integrated design in practice. First of all, sub-question 5.1 focuses on the motivation for integration in the selected cases. Research into the design aspects in relation to integration is part of research sub-question 5.2. Finally, sub-question 5.3 refers to research into the conditions for the integrated design process. In addition, Part III also contains the reflection on the cases from the theoretical perspective as developed in Part I and Part II.

Together, Part I, Part II, and Part II, corresponding to respectively 'Semantics Integrated Design', 'Methodology Integrated Design', and 'Integrated Design in Practice', form the framework for integrated design. The scheme of Figure 3 presents an overview of the research questions in every research part.

Part I: Semantics Integrated Design	
<u>**Chapter 2:**</u>	
Research question 1:	**What is integrated design?**
Sub-question 1.1:	How can design be defined?
Sub-question 1.2:	How can integrated be defined?
<u>**Chapter 3:**</u>	
Research question 2:	**How can integrated design support solving issues of integration?**
Sub-question 2.1:	What defines the construction of the design space for integrated design?
Sub-question 2.2:	How can integrated design determine the space to incorporate value?
Part II: Methodology Integrated Design	
<u>**Chapter 4:**</u>	
Research question 3:	**What is the relation between the methodological structure and the definition of the design space for integrated design?**
Sub-question 3.1:	How did methodological structures for design develop over time?
Sub-question 3.2:	How do currently used methodological structures frame design in different fields of design?
<u>**Chapter 5:**</u>	
Research question 4:	**How can a meta-method for integrated design support solving issues of integration?**
Sub-question 4.1:	What are the key elements of the common ground in methodological structures of integrated design approaches?
Sub-question 4.2:	How can the key elements be translated into a meta-method for integrated design?
Part III: Integrated Design in Practice	
<u>**Chapter 6:**</u>	
Research question 5:	**What are the main findings from integrated design in practice?**
Sub-question 5.1:	What is the motivation for integration?
Sub-question 5.2:	Which design aspects determine how the design is integrated?
Sub-question 5.3:	What are the conditions for the integrated design process?

Figure 3 Research questions per research part

1.4 Aims of this Dissertation

The main aim of this dissertation is to develop a framework for integrated design in order to form a platform for semantic, methodological, and practical discussion and development. Discussion can for example refer to reflection on currently used terminology, design methods, or practices. From this discussion, new integrated design methods and practices can be developed. At the moment, there is not a broad common ground for integrated design that appeals to different fields of design. The framework will consist the principle notes that have to be taken into account in solving issues of integration. Different involved stakeholders and disciplines can then work together along this framework, which therewith forms a platform. The framework is meant to be used along with, and not substituting, currently used disciplinary terms and methods. The exploratory character of this research motivates research into several aspects of integrated design. Therefore, the main aim is divided into different building blocks, which are numbered in correspondence to the numbers of the defined research questions:

1) A description and definition of integrated design as a terminological common ground for discussion about integrated design (research question 1)
2) A conceptual approach that presents how integrated design can support solving issues of integration (research question 2)
3) Overview of the relation between framing in different fields of design and the definition of the design space for integrated design (research question 3)
4) A meta-method for integrated design (research question 4)
5) The main findings from integrated design in practice (research question 5)

Together, these building blocks construct the main aim of this dissertation. Figure 4 presents a scheme of how the different building blocks add to the development of a framework for integrated design.

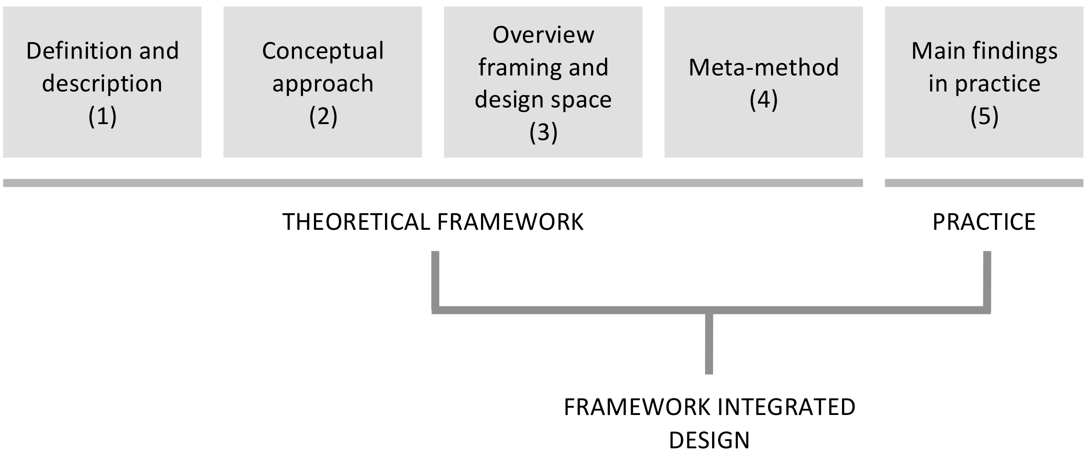


Figure 4 Scheme of how the building blocks add to the development of a framework for integrated design

1.5 Research Methodology

Figure 3 shows an overview of the research questions in this dissertation. This section 1.5 goes into the research methodology with respect to the different research questions. Per research question the research methodology will be explained.

Research Methodology Chapter 2

Chapter 2 is related to research question 1: 'what is integrated design?'. Research question 1 is part of the semantics of integrated design. In order to find an answer on sub-question 1.1: 'how can design be defined?', research is done through literature study with respect to the definition of design. This part of the research is desk research and tries to obtain an overview of definitions of design and their differences and commonalities. The research focuses on the common ground in these definitions to formulate a definition of design to use in the sequence of this dissertation. The definition of design is the definition as derived from literature.

The research with respect to sub-question 1.2: 'how can integrated be defined?' has a similar methodological structure as sub-question 1.1. Sub-question 1.2 is also researched through literature study in order to find an overview of different definitions of the term 'integrated'. 'Integrated' can be stated as a derived term from 'integration'. Therefore the research also investigates the term 'integration'. Both terms 'integrated' and 'integration' are researched in literature in relation to design, but in this description of the research methodology with respect to sub-question 1.2, 'integrated' is used from this point.

Although the definitions for 'integrated' can differ, they refer to a common ground in their relation to design. However, the definitions and interpretations of design can differ in literature. The literature that is studied for the definition of 'design' and the definition of 'integrated' can be the same or related, but this does not have to be the case. The literature research into the definitions of the terms 'design' and 'integrated' are therefore independent, but can show overlap in particular cases.

The sequence of first researching a definition of 'design', and afterwards a definition of 'integrated', is on purpose, because integrated is an addition to design. Therefore, it is useful to first define design in order to understand the relation between the definition of design and different interpretations of integrated.

Research Methodology Chapter 3

Chapter 3 is related to research question 2: 'how can integrated design support solving issues of integration?'. Research question 2 forms together with research question 1 the semantics with respect to integrated design. Sub-question 2.1, 'what defines the construction of the design space for integrated design?' is also researched through literature study. Therefore, this question refers to the construction of the design space for integrated design from a theoretical point of view. Sub-question 2.2, 'how can integrated design determine the space to incorporate value?', is also investigated through literature study, and is related to the answer on sub-question 2.1. Sub-question 2.2 relates the design space to the space to incorporate value. The aim of research question 2 is to come up with a conceptual approach that presents how integrated design can support solving issues of integration. These issues of integration were already illustrated in the introduction, and the conceptual approach has a theoretical ground. Research question 2 is still related to the semantics of integrated design, because it describes the purpose of integrated design. Therefore, the semantics of integrated design in Part I describe what integrated design is from a definition point of view, but also what integrated design is from a utility point of view.

Research Methodology Chapter 4

Research question 3 is the first question with respect to the methodology of integrated design in Part II. Research question 3 is formulated as: 'what is the relation between the methodological structure and the definition of the design space for integrated design?'. It contains terms such as 'design space' and 'integrated design' that were part of research in research question 1 and research question 2. To develop understanding of design methodology in relation to the definition of integrated design, first the development of methodological structures is researched in sub-question 3.1: 'how did methodological structures for design develop over time?'. It illustrates the basic assumptions and interpretations of design that led to methodological structures. This research is done through desk research by investigating literature in design sciences.

In addition to methodological structures that were derived from interpretations of design, methodological structures also frame design on their turn, which is at central stake in sub-question 3.2: 'how do currently used methodological structures frame design in different fields of design?'. To investigate which methodological structures are currently used in different fields of design, different educational employees of different faculties of Delft University of Technology are consulted with the question which design process models and design methods are educated in their curriculum as a base for designing. The methodological structures that are educated can be related to different courses over different years, but develop the understanding of the characteristics of design at different faculties of Delft University of Technology in this research. In the consultation of the educational employees, references will be made to the corresponding literature of design process models and design methods.

Research Methodology Chapter 5

Chapter 5 is about the development of a meta-method for integrated design and is related to research question 4: 'how can a meta-method for integrated design support solving issues of integration?'. In chapter 5, the conceptual approach that was developed in chapter 3 was added with a methodological structure for integrated design. First of all, different integrated design approaches are researched on their methodological structure. These integrated design approaches are obtained through literature study, which can possibly also be derived from the literature study into a definition of integrated in relation to design in chapter 2, or the investigation of the methodological structures for design in chapter 4. The different integrated design approaches will be researched on their differences and commonalities to define a common ground for a meta-method for integrated design. The common ground for the meta-method is therefore obtained through an inductive approach.

Research Methodology Chapter 6

Chapters 2 to 5 form together the theoretical framework for integrated design. The different defined aims in relation to these chapters in section 1.4 show the building blocks of the different chapters for the theoretical framework for integrated design. However, the exploratory character of this research also motivates research into cases in practice. Therefore, chapter 6 is about integrated design in practice, which forms Part III of this dissertation.

The selected cases will be researched through interviews and case documents. The interviews will be organized as open interviews, in which the topics 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process' will come along during the interview. Open interviews with defined topics to discuss are chosen to serve the exploratory character of the research into integrated design as described in this dissertation.

The theoretical framework of the chapters 2 to 5 forms a framework for observation in chapter 6. However, the cases will probably not explicitly refer to all different concepts and terms that were developed in chapters 2 to 5. Therefore, the cases will be described and discussed along the terms that are used by the interviewees and described in case documents. At the end of each case description, the main themes per case and reflection on the cases from a theoretical perspective will be given. Finally, the cases will also be subjected to a cross-case analysis in order to highlight their main commonalities and differences.

1.6 Dissertation Outline

After the 'introduction', the research is divided in three main parts, namely: 'Part I: Semantics Integrated Design' (chapters: 2-3), 'Part II: Methodology Integrated Design' (chapters: 4-5), and 'Part III: 'Integrated Design in Practice' (chapter: 6). Together these three research parts form the framework for integrated design. Chapters 7, 8, and 9 form respectively the 'Conclusions', 'Discussion', and 'Recommendations'. Thereafter, the dissertation closes with the 'References', 'Appendices', 'List of Figures', 'List of Tables', 'Glossary', 'About the Author', and 'Acknowledgements'. The research and dissertation structure from the 'Introduction' till the 'Recommendations' is schematically presented in Figure 5.

More detailed from start to end, chapter 1 forms the motivation and the research framework for this research. Chapter 2 describes a definition of integrated design, which consists of a description of 'design' and a description of 'integrated', in order to form a definition of integrated design as a fundament for discussion and reflection in the case of different interpretations of the term 'integrated design' in different domains in academics and practice. The corresponding question is how these two terms can be related to each other.

After describing a definition of integrated design, chapter 3 is about the incorporation of value through integrated design. This chapter 3 will describe in which way integrated design can support solving issues of integration of human-designed systems in their environment. Chapter 2 and 3 form the definition and interpretation of integrated design and the semantics of integrated design in this dissertation.

In chapters 4 and 5, the methodology of integrated design is at stake. First, chapter 4 is about the relation between the methodological structure and the definition of the solution space for integrated design, researched for the methodological structures for design that are used at different faculties of Delft University of Technology. Thereafter, chapter 5 introduces a meta-method for integrated design that is developed from integrated design approaches in particular fields of application through an inductive approach. The methodological part should function as a common ground on how to create an integrated design, supported by a meta-method for solving issues of integration in multiple fields of application. Chapters 2, 3, 4, and 5 form the theoretical framework for integrated design and can serve as a common ground and a platform for further research, discussion, and development. In chapter 6, the focus is on integrated design in practice, in order to add a practical perspective to the theoretical framework. Chapter 7 forms the concluding part of this dissertation, in which the framework for integrated design is presented. Thereafter, the chapter 8 contains the discussion, and chapter 9 the recommendations for applying integrated design in general, integrated design in academics, and integrated design in practice. As already said, the 'References', 'Appendices', 'List of Figures', List of Tables', 'Glossary', 'About the Author', and 'Acknowledgements' form the final part of this dissertation.

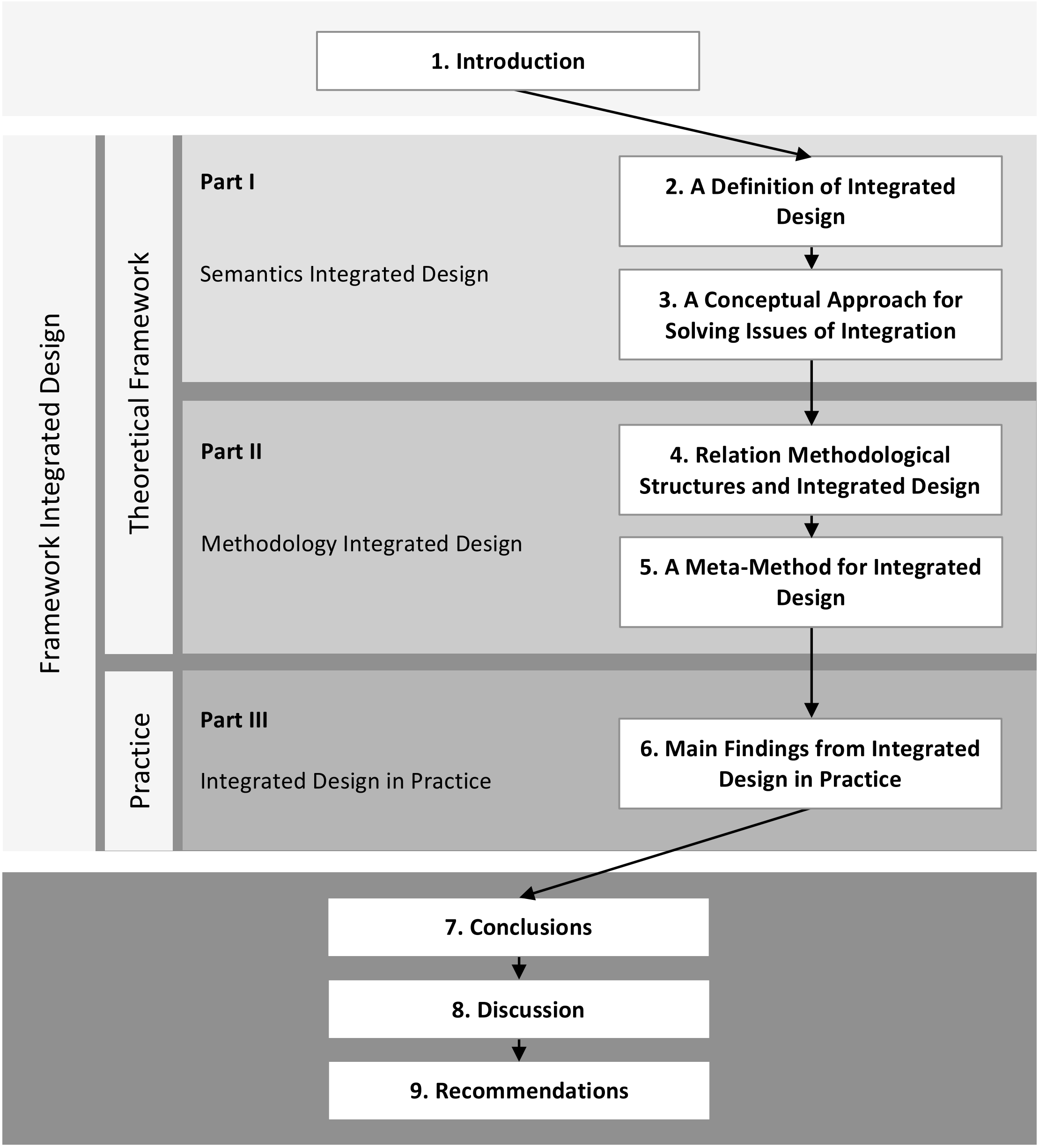


Figure 5 Research and dissertation structure from 'Introduction' to 'Recommendations'

2 A Definition of Integrated Design

2.1 Introduction

In scientific literature, the term 'integrated design' can be found more described in a certain context than explicitly defined. In addition, the way 'integrated' is described in a context of design seems to be diverse. Although different interpretations of integrated design can be applicable for their particular purpose, it can also cause confusion when discussing integration in a broader context of design. In addition, this confusion can also hinder the development of integrated design methods. This chapter addresses research question 1, and corresponding sub-questions 1.1 and 1.2. Research question 1 and sub-questions 1.1 and 1.2 are formulated as:

Research question 1:	What is integrated design?
Sub-question 1.1:	How can design be defined?
Sub-question 1.2:	How can integrated be defined?

The aim of this chapter is to develop a definition of integrated design by investigating scientific literature on the descriptions and definitions of both terms 'integrated' and 'design'. A definition of integrated design can form a theoretical fundament and terminological common ground for discussing integrated design and increase the mutual understanding between designers in different domains. In addition, defining integrated design is also essential for the development of the methodological framework of integrated design.

As an outline for this chapter, section 2.2 develops first of all a definition of design, in line with sub-question 1.1. In section 2.3, sub-question 1.2 is at stake, and a definition of integrated will be given. A definition of 'integrated' is investigated after a definition of 'design', because 'integrated' is an additive of 'design' in this context. Finally, section 2.4 contains the conclusions with respect to research question 1 and sub-questions 1.1 and 1.2.

2.2 A Definition of Design

2.2.1 Diversity and Common Ground in Perspectives on Design

Literature contains many definitions of 'design' that almost all evolved from the rise of design methodology from the sixties of the twentieth century, when design also evolved as a matter of specialization and semantic discussion. Before this time, it was not that people were not designing, but design research was not yet at the level of scientific maturity to make it to a scientific discussion in academics.

However, preliminary to the rise of design methodology from the sixties, some pioneers already explicitly discussed the definition and interpretation of design before this time. One of these pioneers was Walter Gropius, the German architect and founder of the Bauhaus School, who in 1925 already explicitly spoke about design as:

> *'Design is neither an intellectual nor a material affair, but simply an integral part of the stuff of life, necessary for everyone in a civilized society' (Buchanan & Margolin, 1995)*

And in 1947, Gropius spoke about design as:

> *'The term 'design' broadly embraces the whole orbit of man-made, visible surroundings, from simple everyday goods to the complex pattern of a whole town' (Gropius, 1962)*

In these definitions of design, Gropius already expressed design as a matter of meaning and an act of man-made, human centered intervention to structure life. Fundamental in Gropius' descriptions of design is the idea that design is referring to a certain state of life. The conditions to reach this state of life lead to the definition of the design objective.

In addition to the early definitions of Gropius, many more definitions of design can be found in later literature, as given in chronological order in Table 1. The different definitions of design also show the diversity of definitions of design.

Table 1 Overview of definitions of design

Definitions of Design
Asimov (1962): *Decision making in the face of uncertainty, with high penalties for error*
Alexander (1964): *Finding the right physical components of a physical structure* (1)
Alexander (1964): *The process of inventing physical things, which display new physical order, organization, form, in response to function* (2)
Archer (1965): *A goal-directed, problem-solving activity* (1)
Fuller (1965): *Designing has to be a comprehensive, anticipatory science*
Reswick (1965): *A creative activity, it involves bringing into being something new and useful that has not existed previously*
Jones (1966): *Design is goal seeking, problem-solving at its best* (1)
Jones (1966): *The performing of a very complicated act of faith* (2)
Page (1966): *The imaginative jump from present facts to future possibilities*

Matchett (1968): *The optimum solution to the sum of the true needs of a particular set of circumstances*
Simon (1969): *Everyone designs who devises courses of action aimed at changing existing situations into preferred ones*
Jones (1970): *Designing is to initiate change in man-made things* (3)
Papanek (1971): *The patterning and planning of any act towards a desirable, foreseeable end, constitutes the design process* (1)
Papanek (1971): *Design is a conscious and intuitive effort to impose meaningful order…. Design is both the underlying matrix of order and the tool that creates it* (2)
Archer (1979): *Design is, in its most general educational sense, defined as the area of human experience, skill and understanding that reflects man's concern with the appreciation and adaptation in his surroundings in the light of his material and spiritual needs* (2)
Richardson (1984): *Design is a general term, comprising all aspects of organization in the visual arts*
Buchanan (2001): *Design is the human power of conceiving, planning, and making products that serve human beings in the accomplishment of their individual and collective purposes*
Rand (2001): *Design is the method of putting form and content together. Design, just as art, has multiple definitions; there is no single definition. Design can be art. Design can be aesthetics. Design is so simple, that's why it is so complicated*
Love (2002): *Design is a noun referring to a specification or plan for making a particular artifact or for undertaking a particular activity. A distinction is drawn here between a design and an artifact — a design is the basis for, and precursor to, the making of an artifact. Designing is a human activity leading to the production of a design*
Nelson and Stolterman (2002): *Design is the ability to imagine that-which-does-not-yet-exist, to make it appear in concrete form as a new, purposeful addition to the real world*
Hevner et al. (2004): *Design is the purposeful organization of resources to accomplish a goal*
Heskett (2005): *Design is to design a design to produce a design*
Mau (2007): *No longer associated simply with objects and appearances, design is increasingly understood in a much wider sense as the human capacity to plan and produce desired outcomes*
Lawson and Dorst (2009): *Designers typically produce novel unexpected solutions, tolerate uncertainty, work with incomplete information, apply imagination and constructive forethought to practical problems and use drawings and other modeling media as means of problem-solving*

To search if the definitions of design in Table 1 have a common ground, the definitions are investigated on their verbs or acts, and nouns. Verbs or acts are in this context an expression of the intended design process, and nouns as an expression of what the verbs are referring to. Examples of verbs or acts from the investigated design definitions are:

> *Decision-making; finding; problem-solving; anticipatory; creative activity; patterning and planning; ability to imagine; produce; tolerate; apply; conceiving; making; planning; serving; leading; creating; improve; initiate; inventing; accomplishing; plan and produce; appreciation and adaption; putting together; performing*

The diversity in the verbs or acts illustrates the diversity with respect to the intended design process. Next to the research of the verbs or acts, the nouns, which the verbs or acts refer to, are investigated as an expression of the intended output from the design process. The nouns from the investigated design definitions are:

> *Right physical components of a physical structure; goal; optimum solution; preferred ones; desirables, foreseeable end; something new and useful; future possibilities; new, purposeful addition; novel unexpected solutions; collective purposes; change; meaningful order; physical order, organization, form; desired outcomes; material and spiritual needs; art; organization; faith*

As already found for the verbs or acts, the nouns also show diversity in their definition with respect to the intended output of the design process. This shows first of all that the diversity in definitions of design is almost as high as the amount of definitions. Some definitions refer to for example solving a problem, such as the first definitions of Archer (1965) and Jones (1966). Other definitions refer to creating something new, such a defined by Reswick (1965). However, a closer look at the definitions by splitting them in nouns and verbs or acts show that the nouns have in common that they all refer to a different state than the initial state.

Additionally, the combinations of the verbs or acts and the intended reference states have in common that they express intervention to obtain a particular reference state. De Jong (1992) calls this relation between intervention and a particular reference state the 'conditionality', which is corresponding to intervention. To clarify, the 'patterning and planning' towards a, as Papanek (1971) calls, 'desirable, foreseeable end', expresses intervention to obtain a particular reference state as a representation of conditionality. The same holds for instance for Nelson and Stolterman (2002), when they define 'the ability to imagine' as the intervening activity for 'a new, purposeful addition' as a reference state to obtain. Page (1966) even metaphorically visualizes this intervention through obtain a better reference state when he defines design as '...the imaginative jump from present facts to future possibilities'.

The concept of conditionality can be identified implicitly in more literature about design methodology. For example, Simon (1969) refers in his description of design also implicitly to the concept of conditionality when he speaks about the transition from 'what is' to 'what ought to be'. In addition, Schön describes this conditionality as an activity of 'naming' and 'framing' (Schön, 1983), in which Schön elaborates on the description of design as the intervening conditionality for the transition from 'what is' to 'what ought to be' of Simon. The descriptions of design of Simon and Schön can therefore also be interpreted as complementary descriptions of intervention through design.

The concept of 'conditionality' illustrates that design distinguishes itself from other activities in the sense that it represents an intervening activity to make a 'jump' between particular reference states that are defined by the designer, or designer's client(s) and stakeholders. When there is no intervention, the desired reference state would not be a probable future from natural causal relations. The conditionality that represents the intervention to 'jump' between particular reference states in contrast to natural causal relations between reference states is schematized in Figure 6.

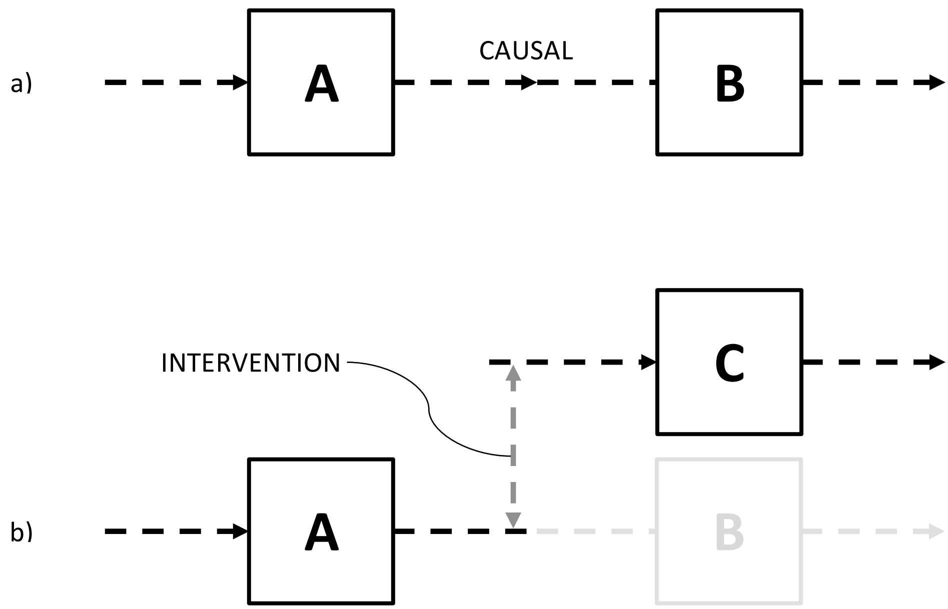


Figure 6 Scheme of 'conditionality'

Reference state A and reference state B are naturally causally related in a) and b), which means that reference state B is considered as a natural probable sequential reference state from reference state A. However, intervention can create a 'jump' from reference state A to reference state C, which creates probably a new reality with new natural causal relations from reference state C. Design distinguishes itself from other activities in the sense that design is about defining reference states and intervention, and not about executing a prescribed intervention with prescribed reference states.

In addition has to be said that the intervention is not referring to design when the problem or opportunity space, and the solution space, are well-defined on beforehand. In that case, the intervention is referring to a 'task' instead of a 'design', as schematized in Figure 7.

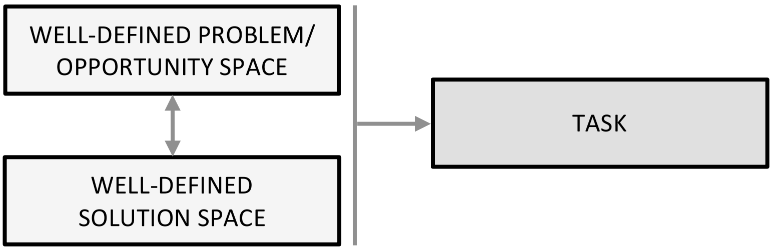
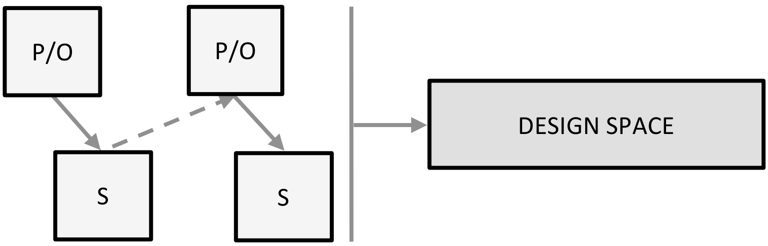


Figure 7 A well-defined problem, opportunity, and solution space form a 'task'

The case of a 'task', as constructed from a well-defined problem or opportunity space and a well-defined solution space, forms a limit for relating intervention to design.

However, as Maher et al. (1996) describe from a problem-solving perspective as the 'co-evolution of the problem-solution pair', the problem space or opportunity space can also be ill-defined. The domain in which the problem or opportunity space and/or the solution space are ill-defined is the domain of the designer. When the definition of the problem or opportunity space, and/or the definition of the solution space, is sub-ordinate to design, the definition of the design space is also subordinate to design, which is schematized in Figure 8.



P = PROBLEM SPACE
O = OPPORTUNITY SPACE
S = SOLUTION SPACE

Figure 8 An ill-defined problem, opportunity, and/or solution space forms the domain for the designer

In the sequel of this chapter 2, the definition of design will be further elaborated. In section 2.2.2, first a closer look at the definition of reference states is explained. Understanding the definition of reference states is essential to understand the development of different design perspectives and definition of design objectives. Different design perspectives and corresponding design objectives can motivate different interventions. In section 2.2.3 the representation of term 'intervention' as applied in this dissertation will be explained.

2.2.2 Design Objectives as the Construction of Different Futures

The scheme of reference states in Figure 6 shows that the definition of reference states is formed by the definition of the current situation, a natural causal situation and a situation to obtain through intervention. The design objective is defined from the relation between these different situations. In this context, De Jong (1992) reflects on different design perspectives and corresponding design objectives in relation to the interplay of three different futures, namely:

- Probable future
- Desirable future
- Possible future

The different futures can construct an interrelation from which a design objective can be defined. From the scheme of De Jong (1992), different design objectives can be defined as a result of the constructed interrelation of futures, as schematized in Figure 9. Different futures can be considered as different reference states. The probable future is the reference state with a central role in this model of Figure 9, because it illustrates the causal relation between for example reference state A and reference state B, as schematized in Figure 6. When a future is not probable, intervention is required as the conditionality for the transition from reference state A to reference state C, as given in Figure 6.

The different perspectives already show the difference in intention with respect to defining the design objective. A probable future, which is not desirable, can be indicated as a problem, and the corresponding design objective is to solve this problem. De Jong (1992) focused in his research on problem solving. A possible future, which is not probable and not yet desirable, is about the creation of designs that appeal to desirables. The design objective is then related to the expression of the imagination to unlock desirables. At last, the interplay of different futures, in which the design objective is constructed as a desirable future, which is not probable, and not yet possible, is focusing on the discovery and realization of means to unlock possible futures. Brenner and Uebernickel (2016) describe in their research into future-oriented design, creation-driven design and discovery-driven design explicitly. In this research, the explicit descriptions of design as creation-driven design and discovery-driven by Brenner and Uebernickel (2016), and problem solving by De Jong (1992), are interpreted as complementary design perspectives.

Although different perspectives can be identified, they all refer to the 'design domain' (De Jong, 1992), as illustrated in Figure 9. The different design perspectives can, in reference to the design domain, be described as:

1) Problem-solving:
A probable future that is not desirable can be defined as a problem. This leads to the need for intervention to solve the problem. An example is the probability of flooding, which is not desirable. Intervention through design can in practice be the design of dikes to reduce flood risk

2) Discovery-driven:
A particular future is desirable, but not probable and possible yet. In this situation intervention is a matter of discovery of possibilities to realize desirables. An example is the desirability to process more data per unit of space on a chip. Intervention design can in that situation be about the transition from two-dimensional to three-dimensional chips to increase the processing of data per unit of space on a chip

3) Creation-driven:
Some futures are not probable and people are not yet aware of desirability. Design is in that context about intervention as the creation of possible desirables that people are not aware of before. An example is the desirability of a tablet computer device or a car. Intervention design is in those situations about the design and introduction of these devices or vehicles, by which people become aware of the desirability

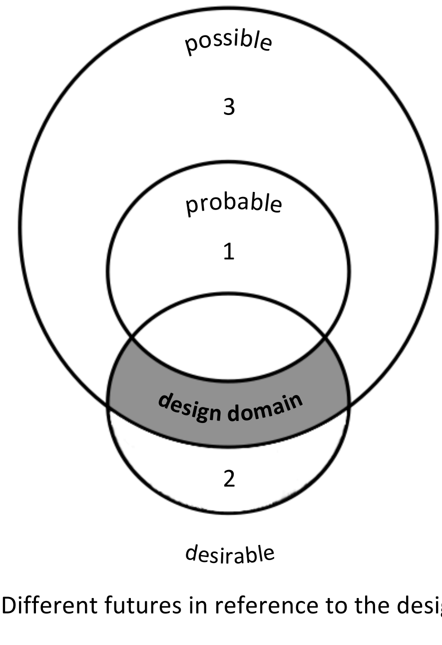


Figure 9 Different futures in reference to the design domain

All three different constructed design perspectives are corresponding to different designer roles and strategies (Taura & Nagai, 2013; Paton & Dorst, 2011), which define different design objectives from their own perspective (Eekhout, 2008). The construction of the design objective as the interplay of different futures can therefore have different appearances. The definition of what is probable, desirable or possible is relative to the person(s) who construct(s) the design objective, and therewith a matter of interpretation.

However, independent of different design perspectives, design is 'heuristic' of character. This means that design does not cause a certain future, but is an attempt to make a desirable future possible (De Jong, 1992). A comparable description of the heuristic character of design can be found in the scheme of Gero and Kannengiesser (2007), when they speak of an expected world after incorporating goals and applying methods that transform desirability into expectation. Maier and Rechtin (2000) differentiate the heuristic process of design in a descriptive part that describes the current situation, but does not indicate a solution, and a prescriptive part that prescribes what might be done.

2.2.3 The Artifact as the Representation of Intervention

In addition to the definition of the different reference states, design also consists of an intervening activity. As already explained, intervention should lead to a 'jump' between different reference states.

This 'jump' between different reference states, translated into the intervention, can be represented by the artifact. The artifact is the human-designed intervention that connects different reference states that were not naturally causally related with each other.

In this dissertation, the term 'artifact' is not exclusively referring to physical artificial objects, but can also refer to other tangible man-made phenomena in domains like business, education, law and medicine (Brenner & Uebernickel, 2016). Additionally, the term 'artifact' is used instead of related terms, such as 'object', 'system', and 'product', because 'artifact' is the only term, in contrast to these other terms, that is intrinsically related to design. An 'object' is referring to the physical presence, but does not have to be artificial or part of design. For example, a rock can also be considered as an 'object', while a rock is not automatically an 'artifact'. With respect to the term 'system', 'artifact' differs from 'system' in the sense that an artifact incorporates a human-designed factor. Maier and Rechtin (2000) define a 'system' as 'a set of different elements so connected or related as to perform a unique function not performable by the elements alone' (p. 27). The definition of Maier and Rechtin (2000) of a 'system' is not intrinsically related to a human-designed factor. A system can in this definition also refer to natural phenomena, such as the weather system. However, the term 'human-designed system' is related to a human-designed factor and can be used in a similar way as the term 'artifact'. Finally, 'product' refers to the result of a process, which can be physical or not. However, as Roozenburg and Eekels (1995) explain, the term 'product' does not have to be intrinsically related to design. A 'product' can also be related to natural processes, such as oxygen as the product of a chemical reaction in a tree leaf. Finally, 'artifact' is the only term that is intrinsically related to design. Zimmerman and Forlizzi (2008) describe that 'the artifact functions as a specific instantiation of a model - a theory - linking the current state to the proposed, preferred state'. In this dissertation, the term 'artifact' is used as the representation of the intervention between different reference states.

2.2.4 A Structure to Describe Design

Although described separately, the definition of reference states and intervention are interrelated with each other in a structure for design. Looking at scientific literature, the interrelation between reference states and intervention is repeatedly described along three components.

A first contribution in this context is given by Dorst (2011), who describes design along the interrelation of the 'what' (thing), 'how' (working principle), and the 'value' (aspired). The 'what' (thing) represents the artifact or intervention, the 'value' (aspired) represents the interplay of different reference states. The 'how' (working principle) represents the way the artifact can lead to the aspired value. Like De Jong (1992) describes design as an attempt to make a desirable future possible, Dorst (2011; 2015) emphasizes the heuristic character of design by using the term 'aspired value'. A scheme of this interrelation of Dorst (2011) is given in Figure 10.

WHAT	**+**	**HOW**	**leads to**	**VALUE**
(thing)		**(working principle)**		**(aspired)**

Figure 10 Schematic structure to describe design
Source: Dorst (2011)

The scheme of Dorst (2011), as presented in Figure 10, is part of a broader design paradigm, starting from the description of 'pattern language' by Alexander (1977). In later publications about design science, we can find comparable design ontology in the Function-Behavior-Structure (FBS) ontology of Gero (1990), elaborated later in Gero and Kannengiesser (2007). In this research, we follow the descriptions of Gero (1990) and Gero and Kannengiesser (2007) of 'function', behavior', and 'structure', in reflection on the critical analysis of the intention of the terms by Dorst and Vermaas (2005). In the FBS ontology of Gero (1990) and Gero and Kannengiesser (2007), 'function' has a similar description as 'aspired value' of Dorst (2011), 'behavior' as 'working principle', and 'structure' as 'thing'. In the work of Tzonis (1992), a frame is constructed of 'form', 'operation', and 'performance', which is comparable to the construction of respectively 'thing', 'working principle', and 'aspired value' in the scheme of Dorst (2011). The comparable terms in literature in relation to 'what', 'how', and 'value' are given in Table 2.

Table 2 Structures to describe design in scientific literature

Comparable terms / Literature	What	How	Value
Dorst (2011)	Thing	Working principle	Aspired (value)
Gero & Kannengiesser (2007)	Structure	Behavior	Function
Tzonis (1992)	Form	Operation	Performance

The embedding of similar forms of schematic structure in the construction of an artifact frame in different publications in scientific literature illustrates the broader applicability of describing a structure for design along three components. Because of the possible broad application of the term 'aspired value' in a stakeholder context, the terminology and scheme of Dorst (2011) are used in the sequence of this dissertation.

2.2.5 Frames and Framing

In the definition of Dorst (2011), design is also value-laden through the incorporation of the aspired value (Paton and Dorst, 2011). Subsequently, the 'working principle' and the 'aspired value' together frame the 'thing' or 'artifact'. Dorst (2015) therefore defines a frame as 'the proposal through which, by applying a particular pattern of relationships, we can create a desired outcome' (Dorst, 2015).

For example, for a certain neighborhood in an urban area holds that this area is prone to flood risk. Without intervention, the probable future is that this area will flood on average once every ten year. The desirable future is a decrease of the flood risk, and the current flood risk is therefore defined as a problem. Stakeholders define the aspired value with respect to flood risk as maximum one flooding every thousand year. At this point, the reference states are defined, and the designer(s) can develop working principles in order to meet the aspired value. Possibly, several working principles like dikes, mounds and buffer areas can be generated in the design process. Together, the aspired value and the possible corresponding working principles frame the intervention, represented by the artifact. In this example, a dike can form the artifact that is developed in relation to the artifact frame.

The example of the design of a dike illustrates the interrelation of the reference states and the intervention along the scheme of Dorst (2011). As part of this process, the example illustrates also framing of the artifact from the interrelation of the working principle and the aspired value, which forms the artifact frame. In Figure 11, the artifact frame is presented as the combination of the 'working principle' and the 'aspired value' in the earlier given schematic structure to describe design.

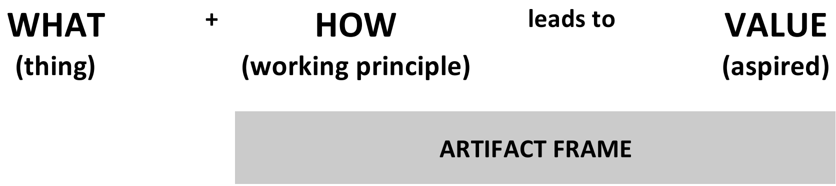


Figure 11 Schematic structure to describe design and the artifact frame

The term 'frame' was initially only a commonly used term in social sciences, gaining momentum with the work of Allport (1940). It was only many years later, the term 'frame' was introduced in design sciences. Donald Schön introduced this term in relation to design theory when he defined a frame as 'the combination of a certain perception of a problematic situation with the adoption of a terminology and a way of reasoning that allows the framer to develop a set of possible actions' (Schön, 1983). Schön linked perception and action in his definition of a frame and defined therewith a frame from a designer perspective. It can be said that Schön actually defined two types of frame, namely the perception frame and the action frame, respectively referring to the frame that is constructed by people's perception, and the frame that shapes how people develop possible actions.

From the perspective of the perception frame, Carton (2007) researched frames in relation to regional policy-making in a multi-actor context. Carton (2007) built on the earlier work of social scientists like Allport (1940), Lakoff and Ferguson (2006), and Gamson and Ryan (2005) in order to define and characterize frames.

Carton (2007) describes a 'frame' briefly as a lens, and researched in this context framing from the perspective of the beholder. From the descriptions of Carton (2007) and Schön (1983), 'framing' can be described from two perspectives, namely:

- Framing from the perspective of the beholder: framing as the cognitive processing to form a mental infrastructure, frame or lens through which someone reasons, recognizes, perceives, valuates, and forms an opinion

- Framing from the perspective of the designer: framing as the awareness of mental infrastructures or lenses, including its own, and the ability to combine this with the adoption of a terminology and a way of reasoning to develop a set of possible actions

In designing, both forms of framing are intrinsically related (Schön, 1983; Rowe, 1987; Lawson, 2005; Paton & Dorst, 2011). The notion of Schön (1983) about people's awareness of their own frames, and possibly also awareness about the possibility of alternative frames, is the fundament for framing from the perspective of the designer.

2.2.6 Types of Frames

The differentiation in 'framing from the perspective of the beholder' of Carton (2007) and 'framing from the perspective of the designer' of Schön (1983) in section 2.2.5 already shows different types of frames. Dorst (2011; 2015) incorporates these frames in his description of the artifact frame. However, also the artifact frame can be typed as a different type of frame. Therefore, design can be described as an interrelated activity that is determined by different types of frames. In this context, Maier and Fadel (2006) describe, in their research into the complexity of design, the 'design system' as a matter of the relation between three major subsystems, namely: 'the designer', 'the artifact' and 'the user'. As mentioned before, 'artifact' is like 'thing' not exclusively referring to artificial physical objects, but can also refer to other man-made phenomena in for example business, education, law and medicine (Ralph & Wand, 2009; Brenner & Uebernickel, 2016). The complex design system between designer, artifact and user is in the research of Maier and Fadel (2006) called the 'designer-artifact-user (DAU) system'. Because the subsystems in the DAU-system of Maier and Fadel (2006) are comparable to the explanation of different types of frames, the interplay of different types of frames can be expressed comparable to the interplay of the subsystems in the DAU-system of Maier and Fadel (2006). 'Sub-systems' are therefore translated into 'elements', and the element 'user' into 'stakeholder'. The derived relational model of different types of frames is illustrated in Figure 12 and is in this dissertation introduced as the 'stakeholder-designer-artifact (SDA) model'.

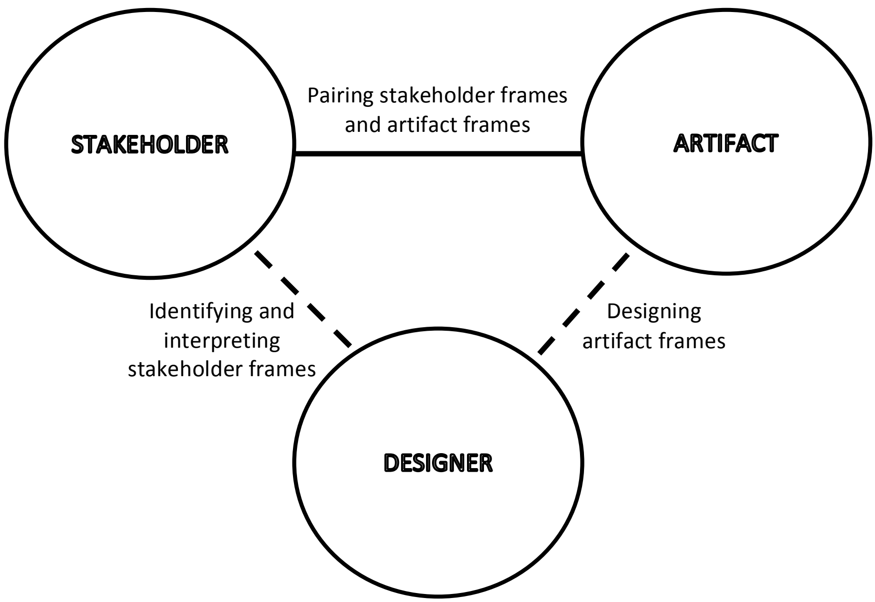


Figure 12 Stakeholder-Designer-Artifact (SDA) model

The relations between the types of frames in the SDA-model can be characterized by particular activities, as illustrated along the connecting lines in Figure 12. In addition, the relations between the designer frame, and the stakeholder and artifact frame can be characterized differently than the relation between the stakeholder frame and the artifact frame. The connecting lines between the designer frame, and the stakeholder and artifact frame are dashed to illustrate that the designer is indirectly related to both frames. The stakeholder frame and the artifact frame are directly related through verification and validation, or for ill-defined problems through what Maher et al. (1996) call, the co-evolution of a problem-solution pair. Maher et al. (1996) do not mention 'frames' or 'framing' in their research, but describe a similar process of designing in relation to different solution spaces from a problem-solving perspective. From a perspective of future-focused design, Greenfield (2006) calls this process 'a co-evolutionary spiral'. The process of co-evolution and pairing can therefore be described referring to 'problem-solving', 'discovery-driven' design, and 'creation-driven' design.

Although the scheme illustrates the differentiation in frame typology, the scheme should be nuanced with respect to the explicit separation of types of frames in design. Designers can be stakeholders and stakeholders can be designers in some situations. Stakeholder and designer frames are then one and the same, but the co-evolutionary process of the pairing of the stakeholder frame and the artifact frame remains the same.

2.3 A Definition of Integrated

Section 2.3 will go into sub-question 1.2: 'how can integrated be defined?'. The research will be done through literature study in order to find a fundament to describe 'integrated'.

2.3.1 Interpretations of Integrated in a Context of Design

Gulledge (2006) states that integration is a common term, but that individuals often even have a different understanding of the meaning of integration in general. Even within certain field of application, as in the example given by Gulledge (2006) of computing, integration can have different meanings in different phases or roles. In scientific literature, few explicit definitions of integration or integrated in relation to design can be found. Dorst (1997) gives in this context the most explicit definition of integration in relation to design, namely:

> *'Someone is designing in an integrated manner when he/she displays a reasoning process building up a network of decisions concerning a topic (part of the problem or solution), while taking account of different contexts (distinct ways of looking at the problem or solution)' (p. 35)*

The definition of Dorst (1997) is a broad description of integration in relation to design. As already said, few explicit definitions of integration or integrated in a context of design can be found in literature. However, despite a lack of explicit definitions of integration and integrated in relation to design, integration and integrated are frequently used as a term to refer to a certain perspective in a context of design.

To clarify, integration and integrated are assumed as different expressions of the same concept. Integration and integrated are therefore both used as reference terms in the literature study of this dissertation to cover a broader use of these terms in the context of design. The interpretations of integration and integrated in a context of design that were found in literature are in random order named as follows:

a) Product architecture
b) Complex systems behavior and modularity approach
c) Modeling
d) Design processes and methods - prescriptive and descriptive methods
e) Mental spaces
f) Modes of reasoning in design
g) Design aspects
h) Knowledge fields
i) Disciplinary boundaries
j) Collaboration
k) Stakeholder involvement through participation
l) Product design and socio-technical development
m) Values
n) Wholeness of system design and environment
o) Shared perceptions
p) Social inclusivity
q) Applications of integrated design methods in specific domains

The named interpretations of integration and integrated in a context of design are briefly described from this point, starting with product architecture.

a) Product Architecture

'Integrated' as a term is in design and systems related literature in multiple studies described in relation to the design of product architecture. For example, Ulrich (1995) describes integrated in relation to the design of product architectures and its consequences for different areas of managerial importance. Sosa et al. (2003) and Eppinger and Browning (2012) describe integrated systems in contrast to modular systems and focus on the design of product architecture as well. Also from a product architecture perspective, Maier and Rechtin (2000) describe the design of the integration of software and hardware. While all these contributions describe 'integrated' in relation to the design of product architectures, they have a different focus.

In design science literature with respect to design methodology and typologies of system architectures, 'integral' can be observed as a commonly used term instead of 'integrated'. 'Integral' is in that context used in contrast to 'modular' (Ulrich, 1995; Sosa, et al., 2003; Hölttä-Otto & De Weck, 2007; Ulrich & Eppinger, 2016). Integral systems architecture is characterized by functions that are spread across components and interactions can occur over interfaces that were not defined on beforehand. Modular systems architecture is characterized by strictly separated in defined components and predefined interactions over predefined interfaces. From the systems architecture design perspective 'integral' is described in contrast to 'modular'. From that perspective, an integral systems structure can be interpreted as a more monocoque system structure in contrast to a more modular system structure. From the perspective of the design of product architecture it seems that 'integral' can be used interchangeable with 'integrated'. Research into possible interchangeable terms for the term integrated will be at stake in a later part of this section.

b) Complex Systems Behavior and Modularity Approach

A different focus of integration is found in Frei and Di Marzo Serugendo (2011). Frei and Di Marzo Serugendo (2011) describe integrated in relation to complexity engineering and use it as a term to discuss if a system can be reduced to the sum of its parts, as claimed by for example Bar-Yam (2003), or that a system can have emergent properties that are not reducible to the its parts. Integration in the interpretation of Frei and Di Marzo Serugendo (2011) is more about the integration of complex systems behavior and a possible modularity approach.

c) Modeling

Another description of integrated in relation to design can be found in Golden (2013). Golden (2013) describes integrated in relation to complex industrial systems that are in the definition of Golden (2013) 'typically artificial objects designed by men, involving a huge number of heterogeneous components', such as hardware, software or human organizations. Integration is in the research of Golden (2013) defined as 'the recursive mechanism to build a system through the synthesis of smaller systems working together'. Golden (2013) focuses in this elaboration especially on the integrated modeling of the complex behavior of the different defined components.

In addition to Golden (2013), Gielingh (2008) elaborates on the term integrated modeling in correspondence with an integrated design activity. Integrated is in the work of Gielingh (2008) about sharing data about products and processes and computational modeling of this data in order to come up with an integrated design. With respect to modeling, Kicinger et al. (2005) describe an integrated research and design support tool, which represents a computer tool that automates and optimizes design processes by integrating state-of-the-art models, algorithms, and analysis and visualization methods. Integrated is from the perspective of Kicinger et al. (2005) also described as the interrelation between different data models in order to support the development of an integrated design.

d) Design Processes and Methods - Prescriptive and Descriptive Models

From a less technical perspective, integration is also described from a perspective of the design process. Roozenburg and Cross (1991) describe integration in relation to the developed differentiation of design processes and design methods between architecture and engineering. Roozenburg and Cross (1991) advocate the re-integration of what they type: prescriptive (engineering) and descriptive (architecture) models.

e) Mental Spaces

As part of the design process, Stacey and Eckert (2010) describe integration in relation to, what Koestler (1964) already called, 'bisociated' (p. 35). Bisociated, as derived from bisociation, represents the integration of different mental spaces as a mental operation underlying creative acts. The integration of the different mental spaces in bisociation is about the elaborating of the problem and current state of the design on the one hand, and creating a new representation on the other hand.

f) Modes of Reasoning in Design

Another interpretation of integrated in a context of design can be found in Pourdehnad et al. (2011). Pourdehnad et al. (2011) describes the integration in relation to different modes of thinking and reasoning in design when he describes the integration of Systems Thinking and Design Thinking.

g) Design Aspects

Integration is also found in relation to design aspects in a context of design. For example, Pugh (1991), and Dorst and Cross (2001) describe integration in relation to design as a matter of integrating a variety of design aspects, such as ergonomics, construction, engineering, aesthetics, and business. Pugh (1991) proposes a model for total design in order to support the incorporation of different design aspects of product engineering in desirable ways.

h) Knowledge Fields

Slightly different from a focus of design aspects is the interpretation of Buijs (2003). Buijs (2003) uses the term integration in relation to product design models that incorporate different knowledge fields, particularly with respect to engineering and commercialization of products.

i) Disciplinary Boundaries

Different aspects are in a specialist spectrum of expertise differentiated in many knowledge fields and show therewith some overlap. In addition, knowledge fields and corresponding design aspects can be differentiated in disciplines of design that have their own research focus with respect to integration. In this context, Stock and Burton (2011) describe the term integrated in relation to 'beyond disciplinary', translated in multi-, inter-, and transdisciplinarity. Stock and Burton (2011) describe multidisciplinary as the practice in which different disciplines work together on an issue, share knowledge and results, but without crossing disciplinary boundaries. In addition, interdisciplinary is described by Stock and Burton (2011) as the practice in which different disciplines work together on an issue and also influence each other in the development of knowledge and results. The boundaries of different disciplines are crossed, but as Neuhauser and Pohl (2015) explain, the disciplines are still defined separately. Finally, transdisciplinary is described as the transcendence of disciplinary perspectives (Stock and Burton, 2011). This transcendence of disciplinary perspectives can result in the development of new theories, and/or methods (Neuhauser and Pohl, 2015).

The design of systems and its corresponding consequences for integration has also its impact on management of these systems. For example, Karstens (2009) describes integrated water management as 'an interdisciplinary field in which many spatial and temporal scales are involved that are closely interrelated' (p. 21). Integration is in the description of Karstens (2009) mainly related to disciplines that all have their particular spatial and time scales that are partly subordinate to design. The discussion of disciplinary boundaries and integration in a context of design seems to be related to multiple perspectives on integration.

j) Collaboration

With respect to collaboration in product development teams, Kleinsmann et al. (2010) describes the integration of knowledge on the actor, the project, and the company level. The emphasis is on the collaboration and corresponding interfaces of collaboration instead on explicit integration of different disciplines, as for example in the research of Stock and Burton (2011).

k) Stakeholder Involvement Through Participation

Collaboration and corresponding interpretation of integration can also refer to stakeholder interaction. Integration with respect to stakeholder involvement is at stake when Nevejan and Brazier (2015) when discussing participatory systems design.

l) Product Design and Socio-Technical Development

Beyond design aspects, knowledge fields, or disciplinary boundaries, integration can also refer to values, as presented in the research of Oosterlaken (2015a), Van de Poel (2015), Cummings (2006), and Manders-Huits (2011).

m) Values

Oosterlaken (2015a) refers to 'Value-Sensitive Design' as an integrated approach of both product design and socio-technical system development. In the interpretation of Oosterlaken (2015a), integration is referring to the integration of a product design in its socio-technical environment. Van de Poel (2015) refers to the incorporation of people's values in discussing integrated in relation to design. The same interpretation can be found in Cummings (2006) when discussing the integration of ethics in design. Manders-Huits (2011) uses integration in reference to the incorporation of values in conception, design, and development in Value-Sensitive Design as well.

n) Wholeness of System Design and Environment

Different interpretations of integration and integrated, from product architectures to the incorporation of values came along, and show range of interpretations with respect to scope and scale. The incorporation of values in the design as an interpretation of integration shows already that integration can also be about a design intervention and its impact on a larger system scope. Reed (2007) focuses on the impact on a larger system scope and calls, from a sustainability perspective, designing systems in interrelationship with their environment a matter of integrated design. Reed (2007) refers in his description of integrated design to interrelated wholeness between system design and environment.

In the publication of Reed (2007), again the term 'integral' is presented, as was also observed in the context of product architecture. In this case, 'integral' refers to a normative status when it is about what is defined as a 'whole' or not and if in that 'whole' comprehends indeed all system aspects.

o) Shared Perceptions

Hertogh and Westerveld (2010) do not especially focus on sustainability as Reed (2007), but are related in the sense that they also describe integration from a larger systems scope perspective. Hertogh and Westerveld (2010) describe integration from a project management perspective as a matter of taking integrating different levels so-called shared perceptions, built up in layers from core to outer layer from respectively large infrastructure project (LIP), physical project, stakeholder network, transport, society.

p) Social Inclusivity

Another perspective on the interpretation of integrated in the context of design is found in Persson et al. (2014) that uses the term integrated in relation to the possibilities of elderly people or people with disabilities to be fully integrated in society. Integrated is from that perspective about social inclusivity, and is referring to a larger system scope as well.

q) Applications of Integrated Design Methods in Specific Domains

In contrast to a broader description of integration in a context of design, other research describes integration especially in relation to a specific design concept. The use of the term integrated to type a concept can for instance be observed in Vriend et al. (2015), in which Building with Nature is described as an integrated approach. Building with Nature is in the description of Vriend et al. (2015) about 'meeting society's infrastructural demands by starting from the functioning of the natural and societal systems in which this infrastructure is to be realized' (p. 160). Another example with respect to infrastructure design can be found in Nijhuis and Jauslin (2015), in which infrastructure is described as landscape and landscape as infrastructure. The descriptions of Vriend et al. (2015) and Nijhuis and Jauslin (2015) of concepts as types of integrated design show more commonalities with the description of integration by Dorst (1997). This is implicitly emphasized with the notion in Vriend et al. (2015) when Building with Nature is expressed as an approach that 'is in line with the need to find different ways of operation and it requires a different way of thinking, acting, and interacting'. This description shows commonalities with Dorst's (1997) expression of integration as a result of 'different ways of looking at a problem or solution' (p. 35). The typology of integrated design for different design approaches in contributions of Vriend et al. (2015) and Nijhuis and Jauslin (2015) show possible applications of integrated design in line with the broad definition of integration in relation to design by Dorst (1997). However, it does not describe a fundamental layer for integrated design and therewith still limited for discussion over different domains with different interpretations. Table 3 gives an overview of the discussed scientific literature and their focus of interpretations of integration and integrated in a context of design. The given literature in Table 3 explicitly names the terms integration and/or integrated in a context of design. The different literature and interpretations are presented in the random order that was followed in the earlier brief explanation of these interpretations.

Table 3 Overview of definitions of integration/ integrated in a context of 'design'

Scientific literature	**Integration/ integrated in design context**
Ulrich (1995) Maier & Rechtin (2000) Sosa et al. (2003) Eppinger & Browning (2012)	Product architecture
Frei & Di Marzo Serugendo (2011)	Complex systems behavior and modularity approach
Gielingh (2008) Kicinger et al. (2005) Golden (2013)	Modeling
Roozenburg & Cross (1991)	Design processes and methods - prescriptive and descriptive models
Stacey & Eckert (2010)	Mental spaces
Pourdehnad et al. (2011)	Modes of reasoning in design
Pugh (1991) Dorst & Cross (2001)	Design aspects
Buijs (2003)	Knowledge fields
Karstens (2009) Stock & Burton (2011)	Disciplinary boundaries
Kleinsmann et al. (2010)	Collaboration
Nevejan & Bazier (2015)	Stakeholder involvement through participation
Oosterlaken (2015a)	Product design and socio-technical development
Van de Poel (2015) Cummings (2006) Manders-Huits (2011)	Values
Reed (2007)	Wholeness of system design and environment
Hertogh & Westerveld (2010)	Shared Perceptions
Persson et al. (2014)	Social inclusivity
Vriend et al. (2015) Nijhuis et al. (2015)	Applications of integrated design methods in specific domains

The different interpretations as presented in Table 3 give an overview of the diversity of these interpretations. However, although the interpretations are differentiated in Table 3 to illustrate the diversity of interpretation, some interpretations of integrated and integration show overlap. For example, Golden (2013) is presented as related to integrated modeling. However, the description of integration by Golden (2013) is also related to integration of complex systems behavior and modularity, as found in Frei & Di Marzo Serugendo (2011).

In addition, the description of integration by Roozenburg and Cross (1991) is also related to modes of reasoning, and Buijs' (2003) integration of knowledge fields is also related to design aspects. Design aspects are in the specialization of expertise in many design cases related to specific knowledge fields that are on their turn related to particular disciplines.

The interpretation of integration by Oosterlaken (2015a) can be characterized by a specific focus on the integration of product design and socio-technical development. However, Oosterlaken (2015a) is also referring to Value-Sensitive Design and is therefore also related to the perspective of values.

In the increasing scope in relation to integration, Reed (2007) and Hertogh and Westerveld (2010) show overlap in interpretation of a large scope. Additionally, in discussing shared perceptions, Hertogh and Westerveld (2010) also relate to integration of disciplinary boundaries as described in for instance Karstens (2009).

Although overlap can be found in some perspectives on integration and integrated in a context of design, and more interpretations can possibly be identified, the investigation gives an overview of the diversity in interpretations, as schematically presented in Figure 13.

The investigation of the interpretations of integration and integrated in a context of design shows that there are many possible frames or lenses with respect to integration and integrated. In accordance with the definition of Dorst (1997) can be said that there are many '....different contexts (distinct ways of looking at the problem or solution)' (p. 35). Integration is therefore about the interrelation of different ways of looking at the problem or solution, and the corresponding interrelation of different frames or lenses.

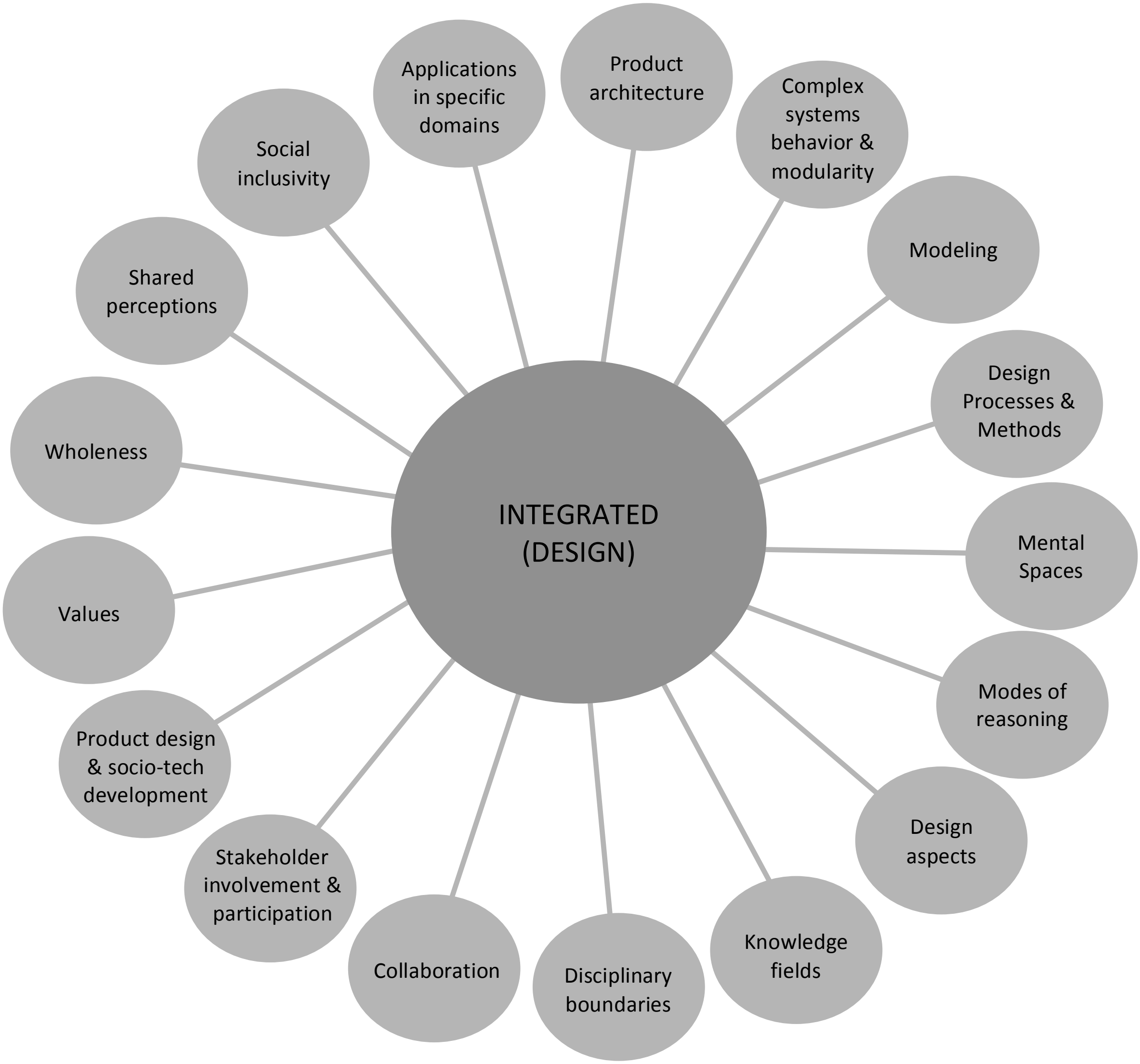


Figure 13 Overview of different interpretations of integration/ integrated in a context of 'design'

Interchangeable Terms for Integration/ Integrated

The elaboration of interpretations of 'integrated' shows that the term 'integrated' is in some cases used interchangeable with related terms. An example is the use of term 'integral' as a substitute of 'integrated'. This is the case in literature with respect to the design of 'product architecture' (Ulrich, 1995; Sosa, et al., 2003; Hölttä-Otto & De Weck, 2007; Ulrich & Eppinger, 2016). Also with respect to the 'wholeness of system design and environment' (Reed, 2007), 'integral' is a common term as a substitute of 'integrated'. In addition, the term 'integral' can also be found in Eekhout (2008), referring to 'integral' as the 'whole' of all design process phases and corresponding scales, instead of a classical 'conceptual' conception in which design is defined in separation from developing and engineering.

However, although the terms 'integrated' and 'integral' are used interchangeable in some cases, in this dissertation a differentiation is made between these terms. For a differentiation between these terms, the contexts for the use of the interchangeable terms are investigated. First of all, with respect to the design of 'product architecture', 'integral' represents the opposite of 'modular'. Therewith, 'integral' refers to a type of product architecture. In addition, with respect to the 'wholeness of system design and environment', 'integral' refers to a normative status when it is about what is defined as a 'whole' or not, and if that 'whole' indeed comprehends all system aspects. Although defined with respect to design process phases and corresponding scales, the use of the term 'integral' by Eekhout (2008) is also related to a defined 'whole'.

The use of the term 'integral' in a context of design in literature gives room for discussion if 'integral' is suitable as a descriptive term. When 'integral' refers to a type of product architecture, the question raises which product architectures are 'integral' and which are not. The same holds for what is defined as a 'whole' or not, and if that 'whole' indeed comprehends all system aspects. What is 'integral' or not becomes a subjective and normative discussion in both cases. Even when product architectures are not typed by 'integral' as a fixed typology, but described as more or less 'integral', this typology is still normative of character.

In contrast to the term 'integral', the definition of the term 'integrated' in a context of design by Dorst (1997) as '....taking account of different contexts (distinct ways of looking at the problem or solution)' (p. 35) is non-normative in its definition. Therefore, 'integrated' seems to be more suitable as a descriptive term than 'integral'.

In a broader context of related terms, Dorst (1997) discusses his definition of 'integration' with respect to different related terms, such as 'combination', 'product integrity', 'integration as a quality', 'coherence', 'optimization', 'holistic', 'creative ideas', and 'concurrent engineering' in relation to his definition of 'integration'. These related terms, as described by Dorst (1997), and additional related terms, as relevant for this dissertation, are given in Table 4.

'Integral' as a term is not mentioned by Dorst (1997), but from the description of 'holistic' can be stated that 'integral' and 'holistic' both refer to a 'whole'. However, 'integral' refers to being part of this 'whole', while 'holistic' refers to an approach in relation to this 'whole'. In addition can be stated that from the discussed terms by Dorst (1997), the descriptions of 'product integrity', 'coherence', 'holistic', and 'creative ideas', all refer to 'wholeness', 'unity', or 'whole'. This brings these terms to the same descriptive difficulties as already discussed for the term 'integral'. Of the other given terms by Dorst (1997), 'integration as a quality' refers also to a subjective and normative discussion, and terms, such as 'combination', optimization', and 'concurrent engineering' all refer to already defined design parts or concepts, which are limiting possibilities for (re)framing.

Another term that is related to 'integrated', but not mentioned by Dorst (1997), is the term 'synergy'. Arnold and Wade (2015) define 'synergy' as 'the interaction of elements in a way that, when combined, produce a total effect that is greater than the sum of the individual elements' (p. 675). Related to the term 'synergy', Gershenson (2007) defines 'emergent properties' as 'the properties of a system that are not present at the lower level, but are a product of the interactions of elements' (p. 168). 'Emergence' can from this definition be derived as 'the system behavior that is not present at the lower level, but is a product of the interactions of elements'. The terms 'synergy' and 'emergence' are related to each other in the sense that a 'synergy' is referring to the positive effect of possible 'emergence'. Both terms are related to 'integrated'. However, the term 'synergy' is also appealing to a normative frame. In addition, 'emergence' as a term is non-normative, but is related to a particular type of interactions of elements. Therefore, both terms 'synergy' and 'emergence' are not suitable as interchangeable descriptive terms of the term 'integrated' in this dissertation. 'Symbiotic' is also not suitable as an interchangeable descriptive term of the term 'integrated' for the reason that 'symbiotic' is appealing to separately related organisms that interrelate in a mutual beneficial way, as described by Mang and Reed (2012). Therewith, the term 'symbiotic' refers to a particular type of relationship between different organisms, which is not per definition applicable to the term 'integrated'.

In addition, two terms, 'inclusive' and 'universal', are added to the investigation of interchangeable terms for 'integrated. Both terms are in design sciences closely related to each other, but Persson et al. (2014) explicitly differentiate the intention of both terms. Persson et al. (2014) describe in this context 'inclusive' as the 'reasonable accessibility to products and/or services in a wide variety of situations' (p. 509). However, 'reasonable' implies a trade-off as part of inclusive design. In addition, inclusive design in design sciences predominantly defined in relation to people's abilities, instead defined in relation to forms of aspired value in a multi-stakeholder context. Because of the implication of trade-offs and specific focus on people's abilities, the term 'inclusive' is not suitable as an interchangeable term for the term 'integrated' in this dissertation.

'Universal' as a term differentiates from 'inclusive' in the way that 'universal' refers to 'products and environments for the needs of people, regardless of their age, ability or status in life' (Persson et al., 2014, p. 508). In that context, 'universal' as a term seems to overcome discussions of trade-off. However, 'universal' also refers specifically to the needs of people instead of a broader systems approach, in which for example also ecological value is incorporated in the focus of design. Therefore, 'universal' is in addition to 'inclusive' also not suitable as an interchangeable term for 'integrated' in this dissertation.

As a result from the investigated related terms can be stated that these terms cannot substitute, but can be applied as a possible frame or lens for the term 'integrated'. 'Integrated' is in this dissertation therefore used as a descriptive term to describe the interrelation between different artifact frames in a non-normative way.

Table 4 Overview of terms that are related to integrated/ integration, as described by Dorst (1997), in combination with additional related terms

Term	Description
Combinative	Combining sub-solutions or features in a design process
Product integrity	'Wholeness' or 'rightness' in a product design
Integration as a quality	Level of integration in a product
Coherence	Purposefulness or 'unity' of a design
Optimization	(Incremental) improvement of an already existing product or design concept
Holistic	Dealing with, and treating something, as an undivided 'whole'
Creative ideas	A sudden occurrence of a 'whole'
Concurrent engineering	Process management technique that seeks to structure the parallel development of different parts (however defined) of a design, the company organization, marketing and production facilities
Integral	As part of a 'whole'
Synergy	The interaction of elements in a way that, when combined, produce a total effect that is greater than the sum of the individual elements
Emergence	System behavior that is not present at the lower level, but is a product of the interactions of elements
Symbiotic	Denoting a mutually beneficial relationship between different organisms
Inclusive	Reasonable accessibility to products and/or services in a wide variety of situations
Universal	Products and environments for the needs of people, regardless of age, ability or status

2.3.2 Frame Compatibility as a Fundament to Define Integrated

Section 2.3.1 showed the diversity in interpretations of 'integrated' in a context of design. Integrated was discussed with respect to related terms and described as a suitable descriptive term for the interrelation between different artifact frames. An elaboration on 'integrated' as a descriptive term in a context of design is at stake in this section 2.3.2.

First of all, in the differentiation of frames, artifact frames are indicated as the type of frames that are designed by the designer, which have a heuristic relation with the aspired value. Secondly, in a setting with multiple stakeholders with possibly multiple forms of aspired value, integrated design is also about the relation between the definitions of different forms of aspired value. To construct the whole artifact frame, the relation between the different working principles is also part of study in integrated design.

Translated into the scheme of artifact frames, as given by Dorst (2011), integrated design is about the coupling of multiple artifact frames. In Figure 14, the relation between any two related 'working principles' and any two related forms of 'aspired value' is schematized as part of any two related artifact frames. Although the scheme of Figure 14 is given for any two related artifact frames, this scheme can also be applied in a broader context with multiple artifact frames.

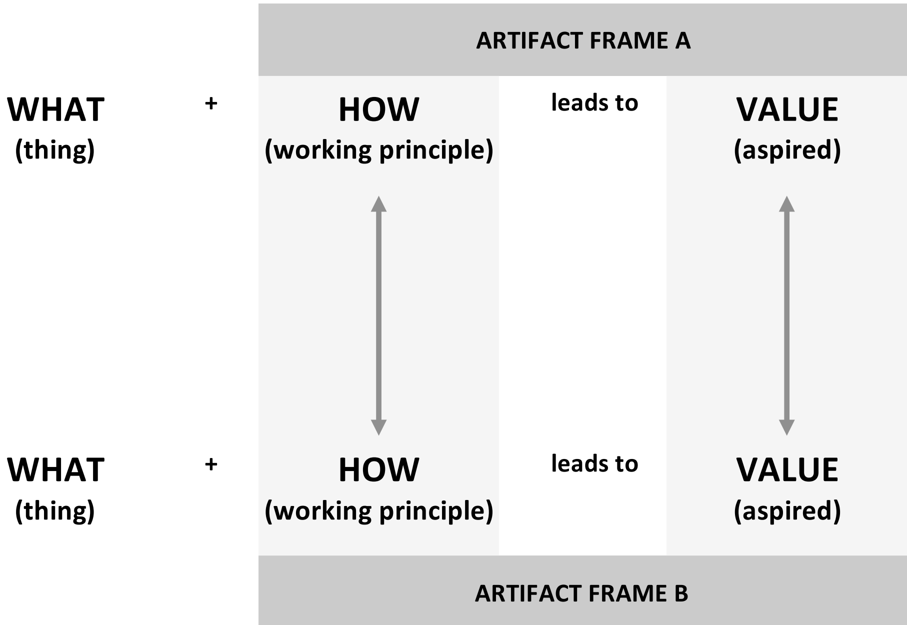
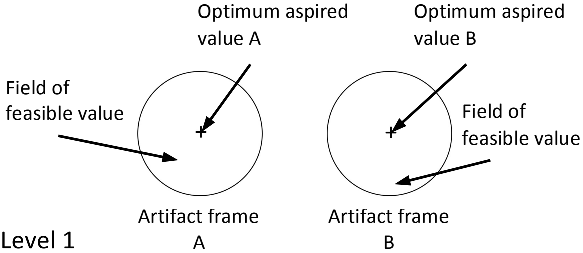
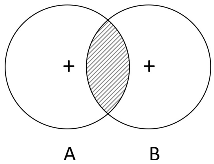
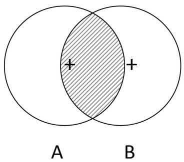
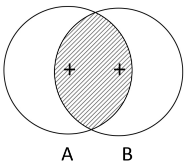
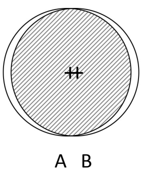


Figure 14 Interrelation artifact frames

Archer (1965) defines from a problem-solving perspective a design problem as 'a complex of thousand or more sub-problems'. Coupling these different sub-problems to different stakeholders, it can be said that a design problem is about the coupling of a complex of thousand or more sub-problems, as defined by stakeholders. To classify this coupling, Archer (1965) identified different levels of compatibility of two related sub-problems, see Table 5. The different levels of compatibility as proposed by Archer (1965) are in this dissertation used as a non-normative classification for integrated design. Non-normative, because it only describes the way different artifact frames are related to each other and does not classify compatibility in a normative or hierarchical way.

Table 5 Frame compatibility for any two related artifact frames

Diagrammatically	Description
 Level 1	Wholly incompatible artifact frames. There is not an overall artifact frame, which embraces both optimum aspired value A and optimum aspired value B
 Level 2	Mutually incompatible artifact frame A and artifact frame B, but there is an overall artifact frame, which incorporates mutually feasible value A and feasible value B
 Level 3	Unilaterally incompatible artifact frame A and artifact frame B. There is an overall artifact frame, which incorporates the optimum aspired value A and a feasible value B, but does not incorporate the optimum aspired value B
 Level 4	Alternate artifact frame A and artifact frame B. There is an overall artifact frame, which may incorporate the optimum aspired value A or the optimum aspired value B, but not both simultaneously
 Level 5	Mutually compatible artifact frame A and artifact frame B. There is an overall artifact frame, which incorporates both optimum aspired value A and optimum aspired value B simultaneously

An example to illustrate the difference in levels of compatibility can be given for the design of a seaport. For the design of this seaport, two main forms of aspired value are at stake, namely the logistical flow value of goods and services and the ecological value in and around the seaport. The port infrastructure forms the artifact that is related to different artifact frames. However, it is possible that the port infrastructure is designed and used in such a way that the logistical flow value is at the cost of the ecological value. The corresponding artifact frames are in that case wholly incompatible, corresponding to compatibility level 1. This means that the port infrastructure design does not incorporate both forms of optimum aspired value simultaneously.

However, when the port infrastructure design can incorporate both forms of optimum aspired value simultaneously, the artifact frames are mutually compatible through the port infrastructure design, corresponding with compatibility level 5. In the case of compatibility level 5, the incorporation of different forms of value can be obtained simultaneously and does not have to come at the cost of each other.

Although Archer describes compatibility in relation to problem-solving for any two related sub-problems, the description of the five levels of compatibility can be applied in a broader context with multiple artifact frames.

2.4 Conclusions

The first part of the theoretical framework is related to research question 1 and sub-questions 1.1 and 1.2. These questions are related to the need for a terminological common ground for integrated design and are at stake in chapter 2. Research question 1 and sub-questions 1.1 and 1.2 are formulated as:

Research question 1:	What is integrated design?
Sub-question 1.1:	How can design be defined?
Sub-question 1.2:	How can integrated be defined?

In order to find an answer for research question 1, the sub-questions 1.1 and 1.2 are discussed where after coming back to research question 1: 'what is integrated design?', which is research question 1 in the development of a theoretical framework for integrated design.

Sub-question 1.1: How can design be defined?

Design can be defined in different ways, which is dependent on the different futures design refers to. The design objective is constructed by the interrelation of the 'desirable future', 'possible future', and 'probable future'. This interrelation of different futures shapes the difference in perspectives on design, from 'problem-solving', to 'discovery-driven', and 'creation-driven'. It shows the reference state dependence of a definition of design.

However, although designers can have different perspectives on design, definitions of design show common ground in the fact that they are all about an intervening conditionality for the transition of one reference state to another or higher system state. Simon (1969) calls this the transition from 'what is' to 'what ought to be'. The artifact represents the intervention for this transition, because the artifact is intrinsically related to design.

From the findings in this dissertation, design can be defined as 'the definition of the reference state dependent intervening conditionality in order to obtain a higher system state'. Design distinguishes itself from other activities in the sense that design is about defining reference states and intervention, and not about executing a prescribed intervention with prescribed reference states. A prescribed or pre-defined intervention with prescribed reference states refers to a 'task'.

Design defined as the 'the definition of the reference state dependent intervening conditionality in order to obtain a higher system state' is subordinate to framing. Framing from the perspective of the designer is an attempt to obtain a set of possible actions that lead to a future that is desirable from the perspective of the beholder. In addition to a designer's own frame, a designer can also create a frame. This leads to the notion that there are different types of frames. There are three types of interrelated frames in design, namely 'stakeholder', 'designer', and 'artifact'. From these three types of interrelated frames, the artifact frame can be defined from the combination of the 'working principle' and the 'aspired value' in relation to an intervention. Framing from the perspective of the designer defines on its turn the designer's definition of design.

Sub-question 1.2: How can integrated be defined?

Scientific literature contains different descriptions and interpretations of 'integrated' in a context of design. A terminological common ground to define 'integrated' is therefore first of all subordinate to the reference state dependency that was already discussed for a definition of design. In addition, integrated is dependent on the interrelation of different artifact frames. When different artifact frames are related to each other, their interrelation can be described along five levels of compatibility, as derived from Archer's (1965) description of the compatibility of any two related sub-problems. From this point of view, a definition of 'integrated' can be derived and formulated as 'the compatibility of multiple artifact frames'. The five levels of compatibility represent a non-normative classification that does not distinct 'integrated' and 'non-integrated', or 'good integration' or 'bad integration'. Integrated is in this dissertation used as a descriptive term to describe the interrelation between different artifact frames. However, different artifact frames can be integrated in a desirable or undesirable way, dependent on the definition of the reference states and the corresponding intervention design.

Research question 1: What is integrated design?

Looking at the conclusions with respect to sub-questions 1.2 and 2.2, it can be concluded that 'integrated design' is the 'framing of the compatibility of multiple artifact frames'. The terms in this definition appeal to a terminological common ground in order to discuss and develop integrated design. Integrated design is in this dissertation used as a descriptive term for framing of the interrelation between different artifact frames. The interrelation between these artifact frames can be described along five levels of compatibility. In this context, the definition of reference states and corresponding intervention is framing the compatibility of different artifact frames.

3 A Conceptual Approach for Solving Issues of Integration Through Integrated Design

3.1 Introduction

In chapter 2, a theoretical fundament for defining integrated design was developed and described. This theoretical fundament aims the development of a common ground for discussing integrated design and the development of a general method for integrated design in chapter 5. However, defining integrated design in itself does not answer the question how integrated design can support solving issues of integration, referring to research question 2. Research question 2 is formulated as:

Research question 2:	How can integrated design support solving issues of integration?

To research the relation between integrated design and the incorporation of value, as derived from research question 2, the corresponding sub-questions 2.1 and 2.2 are formulated as:

Sub-question 2.1:	What defines the construction of the design space in integrated design?
Sub-question 2.2:	How can integrated design determine the space to incorporate value?

The design space is constructed by the interrelated problem space or opportunity space and the solution space, as was elaborated in section 2.2.1. However, the different spaces are formed by constraints. Figure 15 shows a scheme of the relation between the constraints that frame the problem or opportunity space and the constraints that frame the solution space, and the framing of the design space.

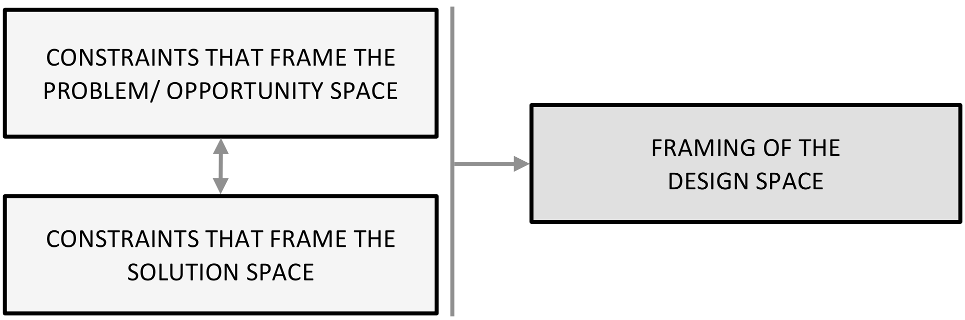


Figure 15 Framing of the design space by constructed constraints from the problem, opportunity, and solution space

To understand what defines the construction of the design space in integrated design, a deeper understanding of constraining and types of constraints is essential. Constraining in design is about framing and therefore also about (re)framing the compatibility between different artifact frames.

The aim of this chapter is to develop a conceptual approach how integrated design can support solving issues of integration as described in chapter 1.

Section 3.2 describes a theoretical fundament on what defines the construction of the design space in integrated design. Section 3.2 refers to sub-question 2.1. Thereafter, section 3.3 describes how design on its turn determines the incorporation of value, which is related to sub-question 2.2. Finally, section 3.4 contains the conclusions with respect to research question 2 and sub-questions 2.1 and 2.2.

3.2 Definition of Constraints in Integrated Design

3.2.1 Balancing Between Too Little Constrained and Over-Constrained

All human-designed systems are structured by constraints. Human-designed systems are partly constrained by intrinsic constraints and cognitive limits, as for example gravity or eye-hand coordination, but are also defined by constraints that are set by stakeholders and designers. Constraining in design is actually about the definition of a design space that leaves room and gives direction for solving problems or opportunities to incorporate value.

Too little constraints can limit an efficient design process because of the high level of complexity (Jost, 2004), or a direction for solution (Stacey & Eckert, 2010). In contrast, a design challenge can also be over-constrained, which is limiting the solution space for solving problems or incorporate value, as also described by Stacey and Eckert (2010). In that case, different constraints can be contradicting with respect to the construction of the solution space. Norman and Stappers (2015) describe contradicting constraints as 'mutually incompatible constraints'. Mutually incompatible constraints can cause issues of integration, which can be differentiated in explicit problems or the lack of opportunities to incorporate value, when different artifact frames are integrated. What is defined as a problem or a lack of opportunities to incorporate value is subjective to the definition of the stakeholders and the designers.

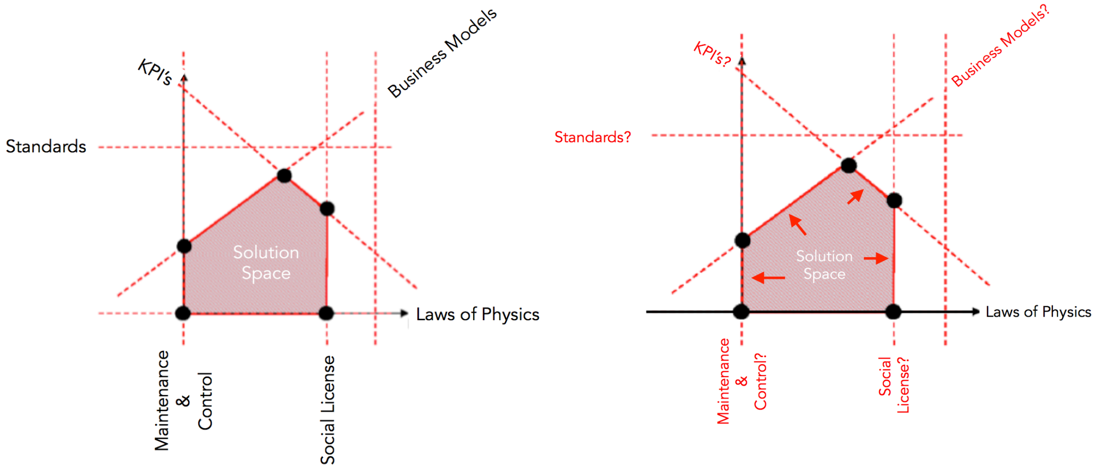
Design is about balancing between too little constrained and over-constrained. An example, in which the challenge of balancing between giving direction for solution and over-constraining is visually expressed, is given in Figure 16. The designed roads in Figure 16 give direction and determine pedestrian traffic at the university campus. However, the situation can appear that someone possibly wants to cross the road halfway, to shorten his or her route, and possibly go straight to a person at a different road. However, the system design does not facilitate a road to cross halfway and the discussion can come up by which constraints the system is defined.


Figure 16 Constraining pedestrian traffic at campus of Ohio State University
Source: Ohio State University (n.d.)

The example of the human-designed system for pedestrian traffic, as given in Figure 16, shows that human-designed systems can facilitate direction on the one hand, while blocking other opportunities on the other hand. The interplay of constraints of for example walking time, aesthetics, green space, chances to meet people, walking distance defines the final design for pedestrian traffic. The final design is developed from the design space, which is constructed by different kind of constraints.

3.2.2 A Typology of Constraints

The example of the design of the roads for the pedestrian traffic in section 3.2.1 illustrates the design challenge of balancing between too little constrained and over-constrained. The design space for the designer is defined by constraints. With respect to for example the solution space, as part of the design space, the relation between constraints and the solution space is schematized for imaginative constraints in situation a) in Figure 17. However, as situation b) in Figure 17 shows, not all constraints are fixed constraints. Some constraints are open for (re)framing, which is illustrated by the red arrows and red lined boundary conditions in situation b). It actually seems that 'laws of physics' are the only fixed constraints for situation b). Situations a) and b) show that constraints can be differentiated along a typological spectrum.



a) Boundary conditions as laws of nature

b) Some boundary conditions are open for (re)framing

Figure 17 Relation between defined constraints and the solution space

With respect to a typology of constraints, several research contributions can be found. Three research contributions show a broader view on the typology of constraints in order to formulate a typology of constraints with respect to integrated design in this research. Biskjaer and Halskov (2013) differentiate in their research about fundamental typologies of constraints three major scientific contributions.

First of all, from a perspective of problem solving, Lawson (2005) developed a cubic model for the typology of constraints. In this model, Lawson defines three axes. The first axis differentiates roles in the design process in 'designer', 'client', 'user' and 'legislator'. The constraints as set by these roles can be 'internal' and 'external' to the control of the designer, which forms the second axis. The third axis differentiates constraints in 'radical', 'practical', 'formal' and 'symbolic'.

A second contribution to the fundamental typology of constraints comes from the work of Stokes (2006), in which constraints and framing are described in relation to enabling creativity in a designer's thoughts and work. While Lawson (2005) describes constraints from a problem solving perspective, Stokes (2006) also describes constraints as possible enablers of creativity, evidenced by the incorporation of a quote of the architect Richard Rogers in relation to his own typological description (Suckle, 1980):

> *'....a major part of any design approach is the way constraints may be absorbed, and whenever possible inverted into positive elements' (p. 107)*

Finally, a third contribution, and most general typology of constraints, is proposed by Elster (2000). Elster (2000) defines three types of constraints from a designer's perspective, namely 'intrinsic', 'imposed', and 'self-imposed'. 'Intrinsic' constraints are for example laws of nature and in-material properties. 'Imposed' constraints are constraints that Lawson (2005) would type as constraints that are out of the control of the designer. As a third type of constraints, Elster (2000) describes 'self-imposed' constraints as constraints that are set by the designer to enable creativity or frame a design.

The fundamental typologies of constraints as described by Lawson (2005), Stokes (2006) and Elster (2000) are different, but can be seen as complementary contributions. A common factor can be found in a differentiation of constraints 'in-the-scope-of-control' of the designer and constraints 'out-of-the-scope-of-control' of the designer. The typology of constraints by Elster (2000) can in this context be used as a general spectrum to type constraints from 'intrinsic' to 'self-imposed'. This spectrum of constraints, derived from the description Elster (2000), is schematized in Figure 18.

Figure 18 Spectrum of constraints

In design challenges, self-imposed constraints can be subordinate to design themselves. However, a designer has to be aware of the self-imposed constraints in order to be able to frame his/her self-imposed constraints. Imposed constraints can be subordinate to design as well, but not always in-the-scope-of-control of the designer. At last, intrinsic constraints are not subordinate to design and intrinsic constraints are therefore given constraints that are out-the-scope-of-control of the designer.

3.2.3 Layered Structure of Constraints

As elaborated in Section 3.2.2, different types of constraints define the design space. These different types of constraints can be subordinate to design, dependent on if they can be typed as 'intrinsic', 'imposed' or 'self-imposed' constraints. When particular constraints are subordinate to design, the design space that is formed by these constraints is also subordinate to design. The question if constraints are intrinsic, imposed or self-imposed can in many cases be answered by analyzing the layered structure of constraints. In the next part, the layered structure of the artifact frame will be researched through research into the layered structure of the aspired value and the working principles.

Layered Structure of Aspired value

The layered structure of the aspired value will be explained along the earlier mentioned example of modern windmill design and planning in chapter 1. When looking at the design and planning of modern windmills, there can be a lot of opposition. However, as already stated earlier, many people are not against a transition to sustainable energy sources and have in common that they implicitly or explicitly support maintaining and developing a livable and clean environment and landscape. Although people can conflict as proponents or opponents of modern windmills, it seems that they show commonalities in their values, such as maintaining a livable and clean environment and landscape. Values seem almost intrinsic of character, while interest and opinions can be imposed or self-imposed. Susskind and Field (1996) translated this observation into a layered structure for value in their so-called Mutual Gains Approach (MGA). The MGA opens possibilities for discussing and increasing the problem space and solution space by searching for common values in situations of conflict with respect to stakeholder interests or opinions. Therefore, stakeholders are likely to find more commonalities in values than in interests and positions.

Parallel to the development of the MGA of Susskind and Field (1996), Friedman (1996) introduced from a design perspective 'Value-Sensitive Design' as an approach to support value-laden design. In Value-Sensitive Design (VSD), designing incorporates an explicit appeal to the layer of 'values', to come up with a balanced design solution (Oosterlaken, 2015b). Van de Poel (2013) proposed a similar 'value hierarchy' in design, with a differentiation in 'values', which are translated into 'norms', which are translated into 'design requirements'. Van de Poel and Royakkers (2011) illustrated VSD with the example of the Eastern Scheldt Storm Surge Barrier that was presented as a design for which two main moral values, safety and ecological care, were balanced in a creative compromise. However, VSD is, as described by Van den Hoven et al. (2015), about the definition of values, the interrelation and hierarchy between values, and moral trade-offs in decision-making in design. However, when looking at the layer of values, it actually seems that most values are not intrinsically conflicting, as the example of the design and planning of modern windmills shows. The question is then why to deal with trade-offs in design when most underlying values are not intrinsically conflicting. This is also expressed in the critique, in for example the publication of Manders-Huits (2011), that Value-Sensitive Design is still about resolving 'conflicting values' through trade-offs.

It seems that many trade-offs between forms of aspired value in integrated design are not caused by conflicting values, but caused by conflicting interests and opinions. Interests and opinions also define the problem space and solution space, but can be (re)framed, because they are in many cases related to imposed or self-imposed constraints that are subordinate to design.

Layered Structure of Working Principles

Besides a layered structure with respect to the definition of the aspired value, also a layered structure for the working principle can be identified. De Hoog et al. (1998) describe a three-layer model for structuring design and planning tasks, and related approaches. The three-layer model consists of a structure from top to bottom of 'occupation', 'networks', and 'substratum'.

Van Schaick (2005) and Van Schaick and Klaasen (2011) elaborate on the three-layer model of De Hoog et al. (1998) and show that different stratified models have a common differentiation. For example, although Heeling et al. (2002) differentiate their layered model with respect to urban planning into five layers, as illustrated in Figure 19, the general structure in scope and scale is similar to the model of De Hoog et al. (1998). The five-layer model of Heeling et al. (2002) consists of a structure form top to bottom of 'use', 'buildings', 'public space', 'urban ground plan', and 'territory/substratum'.

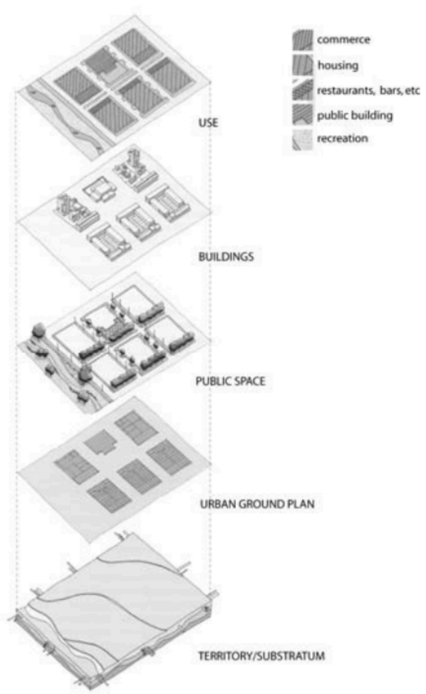


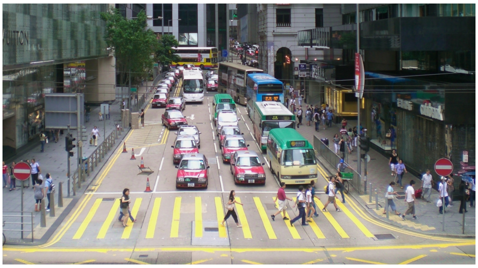
Figure 19 Layered model of Heeling, Meyer, and Westrik
Source: Heeling et al. (2002)

Both models of De Hoog et al. (1998) and Heeling et al. (2002) refer to a layered approach and therewith a layered structure of constraints. This layered structure of constraints can also be analyzed along the typology of constraints that is described in section 3.2.2.

For example, laws of nature, such as gravity, form a fundamental layer of constraints for working principles. Laws of nature define the design space for possible working principles. A less fundamental layer on top of 'laws of nature' can for instance be represented by 'system rules'. System rules can be imposed constraints for the user of that system and define how that system can be used. System rules can be related to physical designs, such as a driving lane for cars, but also non-physical designs, such as a law system or economic system. Although these system rules are imposed constraints for the user of the system, how a system is used within these rules can be self-imposed.

System rules can over-constrain a system, but are normally intended to create benefits from applying structure. The contrasting situations a) and b) in Figure 20 show the benefits of system rules in the case of different traffic flows. It also shows that system rules should be defined for multiple forms of value. While the physical infrastructure is available in the presence of roads in situation a), the lack of system rules for traffic flow cause a system that is not working in a desirable way.

a) Lack of, or neglecting, system rules



b) In accordance with system rules

Figure 20 Structure through system rules
Source: a) Hindustan Times (n.d.); b) DDMLL (2007)

Working principles can be related to different types of constraints. Intrinsic constraints of working principles, such as laws of nature are given, but system rules and how a system is used within the system rules can be subordinate to design. Therefore, a definition of the types of constraints for a system design can possibly show opportunities to increase the design space in order to solve issues of integration through design.

Layered Structure of Artifact Frames

It seems that both the forms of aspired value and the working principles are defined in a context with different types of constraints that can be presented in a layered structure. Together, the aspired value and the working principle form the artifact frame. This implies that the artifact frame is defined in a context with different types of constraints that can be presented in a layered structure. The layered structure for the working principle and the aspired value is schematized in relation to the original scheme of Dorst (2011) in Figure 21.

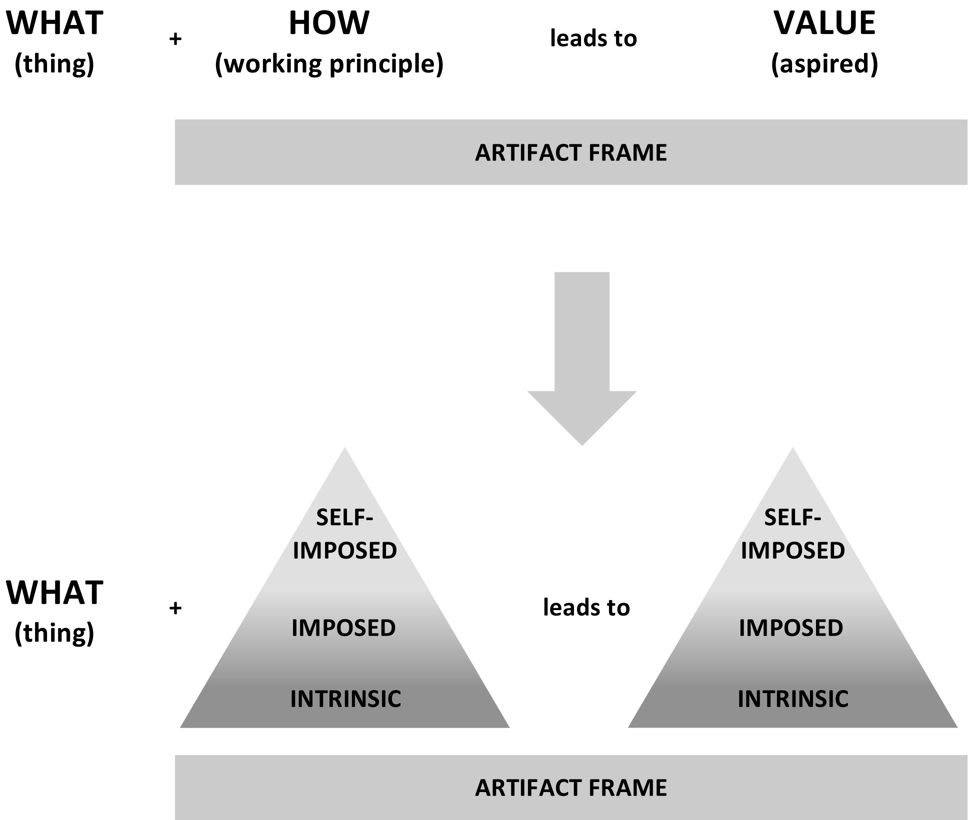


Figure 21 Layered structure of constraints that defines the artifact frame

The layered structure of constraints shows that a part of the constraints for a system design are designs themselves. Therewith, the constraining and compatibility of artifact frames is also partly subordinate to design. Apart from intrinsic constraints, it seems that the incompatibility of artifact frames due to interrelated constraints can be (re)framed through design. However, people's associative cognition and mental models about how a system should look like, and therewith constrained, can be very powerful and act as intrinsic constraints, even when these constraints are self-imposed.

In Figure 22, examples of self-imposed, imposed, and intrinsic constraints are given in hierarchical structure to illustrate the layered structure of constraints in the definition of the working principle and the aspired value, and therewith the definition of the artifact frames. Laws of nature are for example intrinsic constraints that form a frame for system rules. The system rules, such as traffic rules, frame the space for use on its turn. In the context of the definition of the aspired value, values frame the definition of the interests, which frame opinions.

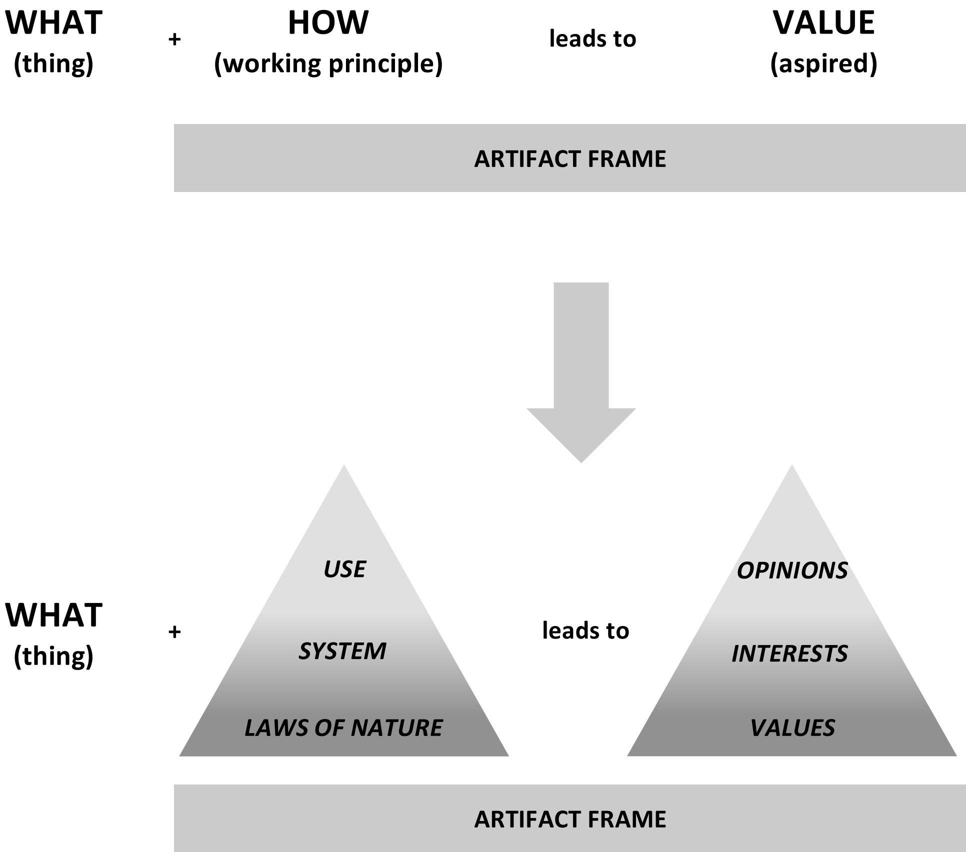


Figure 22 Examples of constraints to illustrate the layered structure of constraints that define the artifact frame

Constraints can stimulate creativity, but also limit opportunities to capture value or even lead to conflict. This is especially of interest in a context of multiple artifact frames in integrated design. The different artifact frames can have different levels of compatibility in interrelation with each other. For cases that artifact frames seem to conflict with each other due to designed constraints, instead of intrinsic constraints, the term 'apparent contradictions' is introduced in this dissertation. 'Apparent' refers to the design component of the contradiction.

A famous example of, what is in this dissertation called an 'apparent contradiction', was given by Ackoff (1978) when he discusses the constitutions of the United States and the Soviet Union and the high political tensions between them during the Cold War. While both national identities were considered as opposite powers, the constitutions of the United States and the Soviet Union seemed relatively similar. However, the systems based on these values were designed and developed in completely different ways. Ackoff (1978) makes in this example the differentiation between 'means' and 'ends', and refers to it as a disagreement between 'means', not 'ends'.

The example of Ackoff (1978) illustrates that in many cases, stakeholders do not intrinsically conflict in terms of values, but conflict in terms of interests and opinions, and the way stakeholders try to meet their interests and opinions through corresponding working principles. The artifact frames seem in those cases be contradictory, but these contradictions are a result of design themselves.

Another example of an 'apparent contradiction' is the seemingly contradiction between for example the 'city' and 'nature'. However, the borders of the city do not bound what is emitted in the city. The city is also part of the ecosystem. In addition, also the example of the 'apparent contradiction' between 'resource' and 'waste' can be given as a matter of design. If something is defined as 'waste' is dependent of the functionality of the designed product. Finally, from a social perspective can be stated that the difference between 'abled' and 'disabled' is also an 'apparent contradiction'. If a person can for example use a telephone or travel by train is to a large extent a matter of design. These examples in different contexts illustrate how design can introduce 'apparent contradictions'.

The description of the layered structure of constraints, and the examples of 'apparent contradictions' as a matter of design, leads to the conclusion that the design space is defined by constraints that are partly designs themselves and these constraints influence the incorporation of value through design. How integrated design can determine the design space to incorporate value is at stake in section 3.3.

3.3 Integrated Design and the Incorporation of Value

The research of chapter 2 resulted that integrated design in general terms can be defined as the 'framing of the compatibility of multiple artifact frames'. The design space for this compatibility was determined by a construction of constraints. When constraints are in the scope of control of the designer, the (re)framing of these constraints can be subordinate to design.

Section 2.2.1 described that when both the problem or opportunity space and the solution space are well-defined, the intervening activity is not referring to the domain of 'design', but to a 'task'. In the case of a 'task', the space to incorporate value is also well-defined, and not subordinate to design. Figure 23 shows a scheme of the relation between the well-defined problem, opportunity, and solution space and the space to incorporate value.

However, when the problem or opportunity space and/or the solution space are ill-defined and subordinate to design, the space to incorporate value is also ill-defined and subordinate to design. This implies that the space to incorporate value can also be (re)framed. The relation between the ill-defined problem, opportunity, and solution space and the space to incorporate value is schematized in Figure 24.

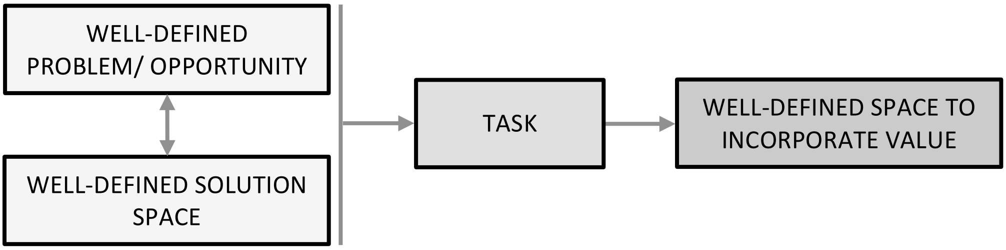
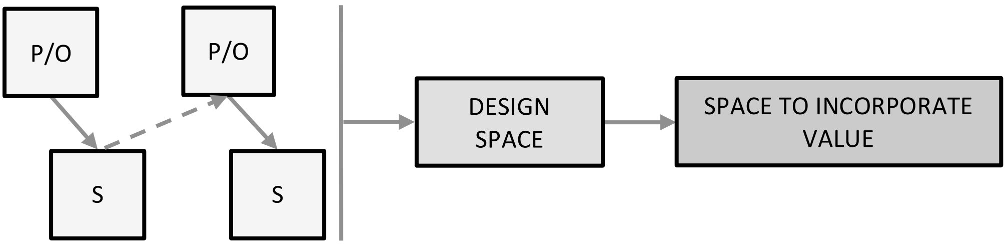


Figure 23 A well-defined problem, opportunity, and solution space form a 'task', which implies a well-defined space to incorporate value that is not subordinate to design



P = PROBLEM SPACE
O = OPPORTUNITY SPACE
S = SOLUTION SPACE

Figure 24 An ill-defined problem, opportunity, and/or solution space form the domain of 'design', which implies an ill-defined space to incorporate value that is sub-ordinate to design

Section 3.2 shows that the design space in integrated design is defined by a layered structure of constraints. Constraints can be typed along a spectrum from intrinsic to self-imposed. The self-imposed constraints imply the possibility for (re)framing the design space. However, although the construction of the design space seems partly open for (re)framing, this does not automatically lead to an increase in the incorporation of value. In this section 3.3, sub-question 2.2 is therefore at stake, formulated as: 'how can integrated design determine the space to incorporate value?'.

The research results from the research into sub-question 2.2 will aim the development of a conceptual approach for integrated design.

3.3.1 Levels of Compatibility and the Incorporation of Value

In table, integrated design is described in relation to five levels of compatibility. In this section 3.3.1, the levels of compatibility, will be reflected on the implications for the incorporation of value from a theoretical point of view. From compatibility level 1 to compatibility level 5, the implications for the incorporation of value through integrated design will be described from this point.

First of all, compatibility levels 1 and 2 can metaphorically be described by the behavior of two connected barrels of water that function along hydrostatic laws. The water will distribute itself over the two barrels and pressure on the water in one barrel will push up the water in the other barrel. Compatibility level 1 and 2 are illustrated in this metaphorical representation in Figure 25 and Figure 26. In terms of value, the increase in value (amount of water in this case) in barrel A leads to an equal decrease in value (amount of water in this case) in barrel B for compatibility level 1, as schematized in Figure 25. In Figure 26, the water is equally distributed over barrel A and barrel B, which presents the situation that half of the optimum aspired value for barrel A and half of the optimum aspired value for barrel B can be obtained when both artifact frames are integrated.

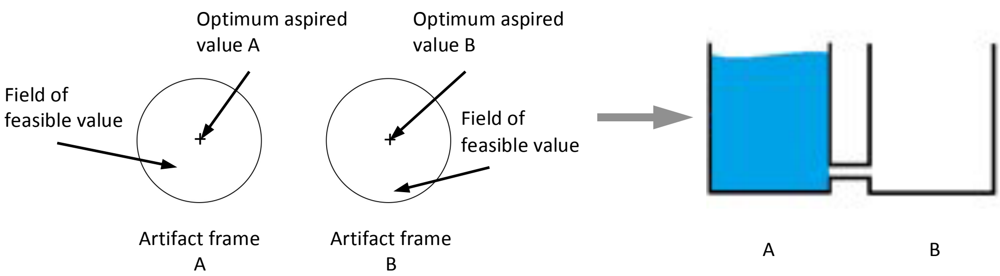


Figure 25 Value incorporation compatibility level 1 - concession with respect to one of the artifact frames

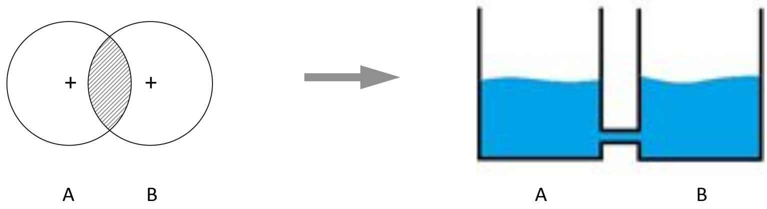


Figure 26 Value incorporation compatibility level 2 - compromise between two related artifact frames

The metaphorical representation by connected barrels that follow hydrostatic laws is also applicable for compatibility level 3 and 4. In the case of compatibility level 3 and 4, at least one optimum aspired value can be incorporated. However, neither for compatibility level 3 and 4, the optimum aspired value can be obtained simultaneously. Therefore, the 'exchange of value' after trade-offs, as explained in the introduction in chapter 1 is still at stake. Therefore, integration of multiple artifact frames along compatibility level 3 or 4 does not solve issues of integration.

The only compatibility level that does incorporate the optimum aspired value of multiple artifact frames in integration simultaneously is compatibility level 5. The incorporation of value when integrating multiple artifact frames does not refer to a concession, compromise, or need for compensation with respect to at least one of the artifact frames.

From compatibility level 1 to 5, the artifact frames are tightly coupled. However, from compatibility level 1 to 4, the tight coupling refers to trade-offs and the exchange of value. For compatibility level 5, the tight coupling refers to the situation in which forms optimum aspired value of different artifact frames are obtained simultaneously. To explain this change in perspective, the benefit of compatibility level 5 can be illustrated along the old metaphor of the discussion between two persons if the number they are looking at is a 6 or a 9, as given in Figure 27. In the case of compatibility level 5 in a context of integrated design, the discussion is not if the artifact frame should be interpreted as a 6 or a 9, but both interpretations of artifact frames are possible and valid at the same time. In other words, as 6 and 9 are referring to the value of a particular interpretation of an artifact frame, instead of value 6 or 9, metaphorically now value 15, as the sum of value 6 and value 9, can be realized at the same time and within the same space, for several stakeholders and multiple interpretations of artifact frames. While Figure 27 is referring to the sum of explicit numbers, the situation can also be applied to a context of qualitative and less explicit forms of value.

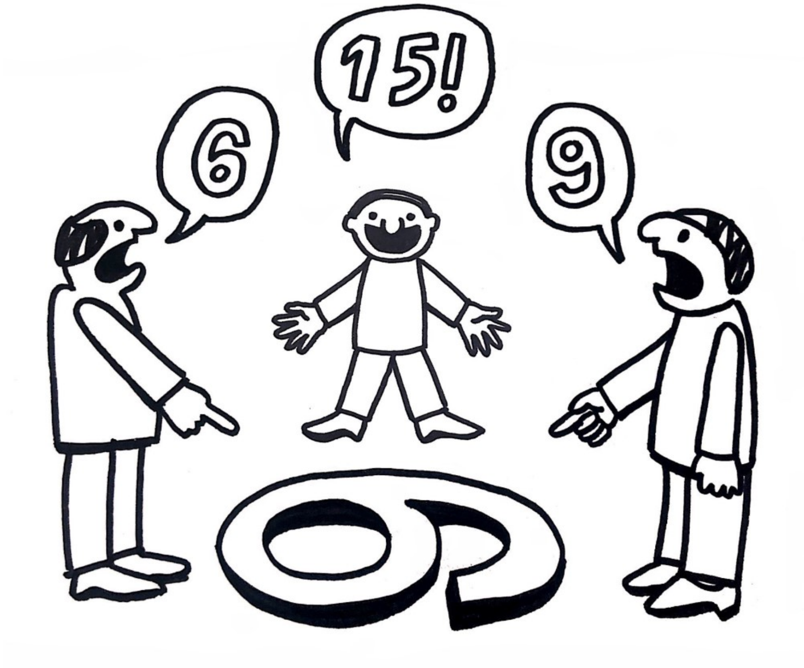
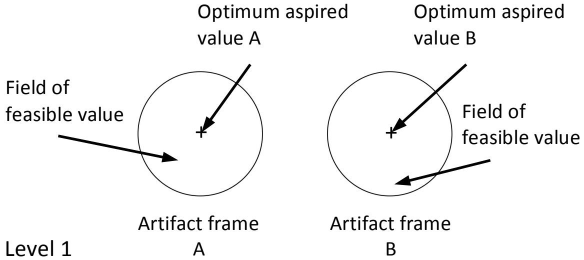
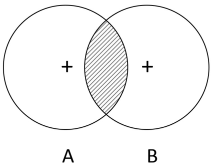


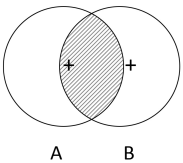
Figure 27 Value incorporation compatibility level 5 - mutual compatible artifact frames can lead to the optimum aspired value simultaneously
(Illustration by Antoine Stöhr)

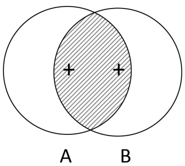
An overview of the defined levels of compatibility related to the implications for the incorporation of value is given in Table 6. Table 6 is an extension of Table 5 that was presented in section 2.3.2.

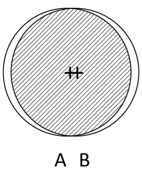
Table 6 Frame compatibility related to the incorporation of value

<table>
<tr><th>Diagrammatically</th><th>Description</th><th>Incorporation of value</th></tr>
<tr><td>


Level 1</td><td>Wholly incompatible artifact frames. There is not an overall artifact frame, which embraces both optimum aspired value A and optimum aspired value B</td><td>Concession with respect to the optimum aspired value of artifact frame A or artifact frame B when integrated</td></tr>
<tr><td>


Level 2</td><td>Mutually incompatible artifact frame A and artifact frame B, but there is an overall artifact frame, which incorporates mutually feasible value A and feasible value B</td><td>Artifact frame A and artifact frame B are both confronted with a concession when integrated; compromise</td></tr>
<tr><td>


Level 3</td><td>Unilaterally incompatible artifact frame A and artifact frame B. There is an overall artifact frame, which incorporates the optimum aspired value A and a feasible value B, but does not incorporate the optimum aspired value B</td><td>Only for artifact frame A, the optimum aspired value can be obtained when integrated</td></tr>
<tr><td>


Level 4</td><td>Alternate artifact frame A and artifact frame B. There is an overall artifact frame, which may incorporate the optimum aspired value A or the optimum aspired value B, but not both simultaneously</td><td>Only for one of the artifact frames the optimum aspired value can be obtained when integrated</td></tr>
<tr><td>


Level 5</td><td>Mutually compatible artifact frame A and artifact frame B. There is an overall artifact frame, which incorporates both optimum aspired value A and optimum aspired value B simultaneously</td><td>The optimum aspired value for both artifact frame A and artifact frame B can be obtained simultaneously when integrated</td></tr>
</table>

The different levels of compatibility are now described from a value point of view and show that the simultaneous incorporation of the optimum aspired value for different artifact frames can only be obtained by integration along compatibility level 5. Section 3.3.2 will elaborate on the corresponding design approach to obtain compatibility level 5 between different artifact frames through integrated design.

3.3.2 Dissolution Through Design

Section 3.3.1 related the defined levels of compatibility in integrated design to the incorporation of value. The investigation in section 3.3.1 shows that only for compatibility level 5 the optimum aspired value for multiple artifact frames can be obtained simultaneously. In this section 3.3.2, the research is about if compatibility level 5 can be translated into a concept design approach for integrated design in order to solve issues of integration. As found in literature, Ackoff (1978; 1999) describes four ways of dealing with conflicts that are also applicable to the defined issues of integration as described in chapter 1. A short explanation of these four ways of dealing with conflicts, according to Ackoff (1978; 1999), is given from this point:

- Absolution
  To ignore a problem or mess and hope it will take care of itself and go away of its own accord (Ackoff, 1999)

- Resolution
  To do something that yields an outcome that is good enough, that satisfies. In this situation, conditions are accepted and satisfaction lies in the distribution of gains and losses that is acceptable to the participants (Ackoff 1978; 1999)

- Solution
  To do something that yields or comes close as possible to the best possible outcome, something that optimizes, but serves a certain optimal sub-solution. In this situation, competition is at stake with a win-or-lose game under certain defined conditions (Ackoff, 1978; 1999)

- Dissolution
  To redesign either the entity that has the problem or mess, or its environment, in such a way as to eliminate the problem or mess and enable the system involved to do better in the future than the best it can do today, in a word, to idealize. In a situation of dissolution, conditions that cause the conflict are changed to disappear. In dissolution of conflict, neither participant loses. Both obtain an optimal solution without compromises (Ackoff, 1978; 1999)

Of these four ways of dealing with conflicts, as defined by Ackoff (1978; 1999), the descriptions show that dissolution is the only approach that does relate to the optimum aspired value for multiple artifact frames simultaneously. Dissolution can therefore be indicated as the representation of the design approach that is related to compatibility level 5 in integrated design. Dissolution of trade-offs between different forms of value also implies dissolution of the exchange of value in cases of value hierarchy. In addition, dissolution also gives opportunities to incorporate less explicit forms of value through design. An example case of dissolution for the integration of a hydraulic coastal protection system and an ecological system will illustrate how dissolution looks in practice.

Example case: The Sand Motor, Kijkduin

For the coastal maintenance of the Dutch coastline, a new approach was applied through the design of the Sand Motor, which was constructed in 2011. The Sand Motor forms a large artificial peninsula of about 300.000 m^3 of sand. The idea is that the sand gradually distributes in Northern direction along the coast, to reinforce the Dutch coastline (Rijkswaterstaat, 2016). Traditional engineering measures would mean more local reinforcement interventions, but in many cases at the cost of ecological value. The working principle of the gradual process of distribution gives the ecosystem possibilities to adapt and develop. Because the natural flows are slowly gradual processes, the process of coastal reinforcement is slow and gradual as well, which makes it necessary to start early with a certain scenario for reinforcement. This in contrast to short-term direct sand supplementation that is precise, but its working principle is not always compatible with ecological working principles. Figure 28 shows the change in shape of the Sand Motor from 2011 till 2016. Additionally, the Sand Motor also creates value in terms of possibilities for different forms of recreation, such as walking, bathing and kite surfing.

Figure 28 Gradual development Sand Motor 2011-2016

Source: Rijkswaterstaat (2016)

The traditional engineering approach of directly applied local reinforcement of the coastline caused an incompatible relation for the mutual optimum aspired value regarding 'flood risk reduction' and 'ecosystem quality'. In contrast, the design of the Sand Motor incorporates a working principle that is leading to the mutual optimum aspired value for 'flood risk reduction' and 'ecosystem quality'. The design of the working principle of the Sand Motor leads to a relation between the different forms of aspired value in which they do not have to come at the cost of each other any more. Figure 29 gives the schemes in relation to Table 6 for the levels of compatibility for a traditional solution, which can for example be characterized by compatibility level 3, versus the Sand Motor, which can be characterized by compatibility 5.

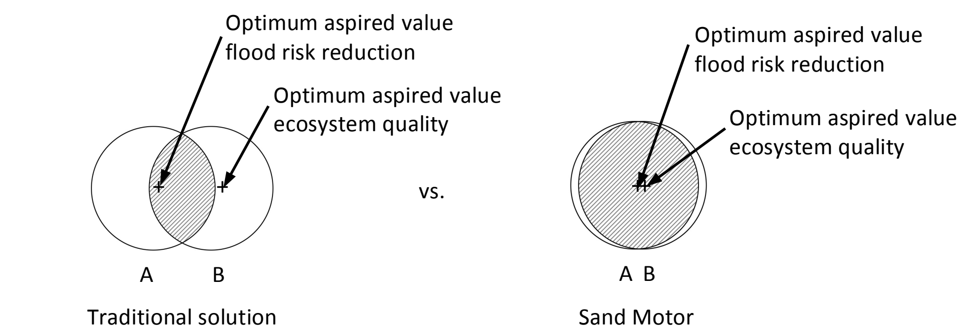


Figure 29 Schemes of the levels of compatibility for a traditional solution (compatibility level 3) versus the Sand Motor (compatibility level 5)

The issue of integration is dissolved through the design of the Sand Motor. In the case of the Sand Motor, the designers were able to integrate different artifact frames in accordance with compatibility level 5. When dissolution between the hydraulic coastal protection system and the ecological system can be obtained, the design also dissolves trade-offs between the aspired value of a 'flood risk reduction' and the aspired value of 'ecosystem quality'. Therewith, a hierarchy and corresponding possible power play between stakeholders that have an interest in one of the forms of aspired value is also dissolved. ■

3.3.3 A Fundament for Abundance

Section 3.3.2 described dissolution as a concept design approach for integrated design in order to solve issues of integration. In addition, if one form of value does not come at the cost of another form of value, when multiple artifact frames are integrated through design, dissolution also implies a way to create a system state that gives opportunities for abundance with respect to the relation between different forms of aspired value. Jacques Ellul expressed in 1964 a similar thought already as:

> *'...reality is itself a combination of determinisms, and freedom consists in overcoming and transcending these determinisms' (in Jones, 1992, p. 26)*

The 'combination of determinisms' can also be translated by the 'combination of constraints'. The constraints of multiple artifact frames form the design space for integrated design. Again referring to the example of The Sand Motor, when the optimum aspired value for the hydraulic coastal protection system and the optimum aspired value for the ecological system can be obtained simultaneously through integrated design, issues of dissolution are dissolved. The design spaces of the different artifact frames do not constrain each other any more, because they are one and the same. In that case, the integrated design facilitates possibly abundance with respect to the relation between different forms of aspired value.

The elaboration from a terminological common ground for integrated design, and the definition of different levels of compatibility for integrated design show that compatibility level 5 is related to dissolution. In addition, dissolution forms a design approach to obtain abundance for the relation between different forms of aspired value. A conceptual approach on how integrated design can lead to a state of abundance for the relation between different forms of aspired value is schematized in Figure 30.

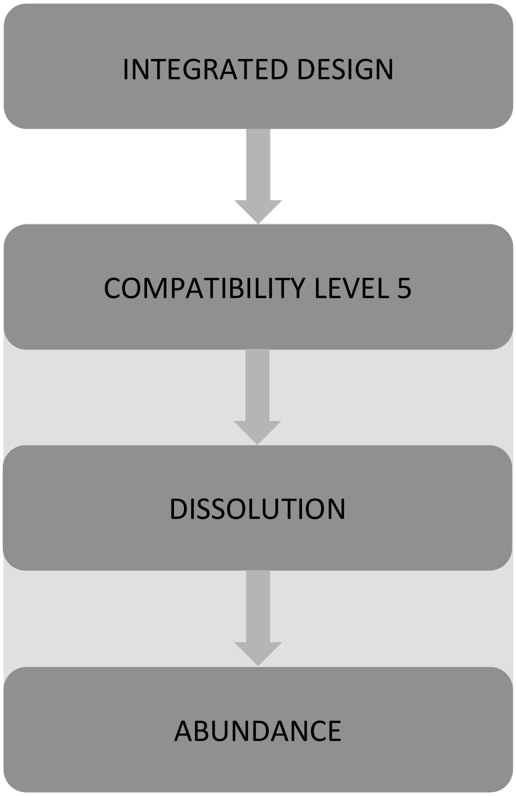


Figure 30 Conceptual approach on how integrated design can lead to a state of abundance

3.4 Conclusions

A terminological common ground for integrated design does not automatically imply solving the issues of integration as discussed in chapter 1. Therefore, this dissertation also elaborates on the question how integrated design can support solving issues of integration, which forms research question 2. To understand how issues of integration can be related to design, but also possibly be solved through integrated design, sub-questions 2.1 and 2.2 are defined. Research question 2 and corresponding sub-questions 2.1 and 2.2 are formulated as:

Research question 2:	How can integrated design support solving issues of integration?
Sub-question 2.1:	What defines the construction of the design space in integrated design?
Sub-question 2.2:	How can integrated design determine the space to incorporate value?

First of all, sub-question 2.1 and 2.2 will be discussed, where after a conclusion with respect to research question 2 can be constructed from these sub-questions.

Sub-question 2.1: What defines the construction of the design space for integrated design?

The design space in the case of integrated design is defined by the constructed design space of different interrelated artifact frames. The components that construct the artifact frame, respectively the working principle and the aspired value, have a layered structure. Research into this layered structure leads to the conclusion that the compatibility of frames can differ on different layers. For example, while forms of aspired value are conflicting, values do not have to conflict. The same holds for system rules versus laws of nature in the context of working principles. The construction of constraints that defines the design space is therefore related to a typology of constraints that is ranging from respectively 'intrinsic', 'imposed', to 'self-imposed' constraints. These types of constraints define the design space. However, 'imposed' and 'self-imposed' constraints can be subordinate to design themselves, when the constraints are in the scope of control of the designer. This implies possibilities for (re)framing the design space. When it comes to the compatibility of multiple artifact frames, the design spaces of these artifact frames can also constrain each other. When the constraints are imposed or self-imposed, these constraints can be subordinate to design and therefore possibly (re)frame the compatibility of interrelated artifact frames and the design space for integrated design.

Sub-question 2.2: How can integrated design determine the space to incorporate value?

The space to incorporate value is different from the design space. The design space can be large, while the space to incorporate value is limited, and vice versa. The design space in the case of integrated design can be described as the constructed design space of different interrelated artifact frames. The compatibility of these interrelated artifact frames can be differentiated into five levels. For compatibility level 1 to 4, the integration of different artifact frames limits the space to incorporate value. However, compatibility level 5 is different from the other levels of compatibility with respect to the incorporation of value. Integrated design in accordance with compatibility level 5 gives the ability to dissolve issues of integration, which were differentiated in 'problems' and the 'lack of possibilities to incorporate value'. What is defined as a 'problem' or a 'lack of opportunities to incorporate value' is subjective to the definition of the stakeholders and the designers in this context.

The corresponding design approach to obtain compatibility level 5 can therefore be represented by 'dissolution'. With this design approach, trade-offs, exchange of value in cases of value hierarchy, and for example the lack of possibilities to incorporate less explicit forms of value, can be dissolved. Even more, integrated design in correspondence with compatibility level 5 can create a state of abundance with respect to the relation between different forms of aspired value.

Research question 2: How can integrated design support solving issues of integration?

Issues of integration can appear when different artifact frames limit each other's space to incorporate value in the case of integration. The compatibility of different artifact frames can be described along five levels. In relation to integrated design, compatibility level 1 to 4, all refer to conflicting constraints in the construction of the space to incorporate value. Compatibility level 5 is different from compatibility level 1 to 4, because in the case of integrated design in accordance with compatibility level 5, value conflicts and the lack of possibilities to incorporate value can be dissolved.

To (re)frame the interrelation between different artifact frames, the constraints that define the combined design space should be reflected on a typology of constraints. Three types of constraints are defined, namely 'intrinsic', 'imposed', and 'self-imposed' constraints. 'Imposed' and 'self-imposed' constraints can be subordinate to design themselves, when they are in the scope of control of the designer. When the constraints that define the design space are partly subordinate to design, it implies that the compatibility of different artifact frames can also be subordinate to design. When a designer is able to create integration between interrelated artifact frames in accordance with compatibility level 5, the designer is also able to dissolve constraints that limit the space to incorporate value with respect to these interrelated artifact frames.

Integrated design can support solving issues of integration when mutually incompatible constraints can be (re)framed in such a way that artifact frames become compatible in accordance with compatibility level 5. In that case, issues of integration will be dissolved and a state of abundance with respect to the relation between different forms of aspired value can be created.

4 Framing Integrated Design Through Methodological Structures

4.1 Introduction

In chapters 2 and 3, a definition of integrated design, and a conceptual model for solving issues of integration through integrated design were developed. These chapters form the semantics of a framework for integrated design.

During the research into a definition of integrated design, conversations about integrated design with design related academics at different faculties of Delft University of Technology resulted in the observation that different fields of design use the term 'integrated design', without elaborating this term explicitly. In addition, different faculties at Delft University of Technology are related to the design of different artifacts, such as airplanes, cars, water barriers, or buildings. This informal observation motivates therefore research into the relation between design in different fields of design and their framing of integrated design. Because integrated design seemed to be used as a term at different faculties without explicit definition, the focus of this research will be on the methodological structure that frames design in different fields of design.

To explain what is meant with 'methodological structures', the differentiation aspect of design methodology of Eekhout (2008) is applied. Eekhout (2008) differentiates methodological structures in three different aspects, as schematized in Figure 31.

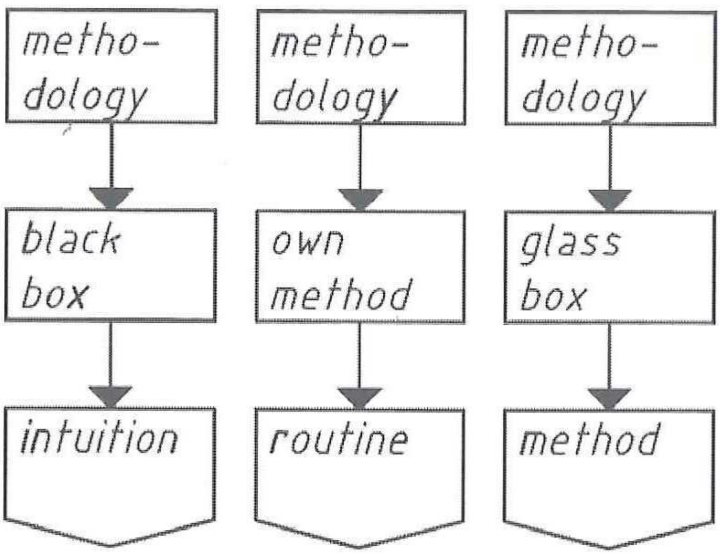


Figure 31 Three aspects of design methodology
Source: Eekhout (2008)

Eekhout (2008) describes 'intuition', 'routine', and 'method' in relation to design methodology. In practice, design will contain a mix of these different aspects. However, in this dissertation, predominantly the explicit methodological structures that refer to the 'glass box' of Eekhout (2008) in Figure 31 are at stake, because these explicit methodological structures show characteristics of how design is educated and framed in theory. The explicit methodological structures that are investigated in this chapter 4 are design process models and design methods. However, these explicit design process models and design methods can also develop routine and facilitate room for intuition. From that perspective, intuition and routine are respectively influenced by and in some cases derived from explicit methods.

As described in section 3.3, the design space frames the space to incorporate value. The ill-defined character of the design space requires methodological structures to guide the design process. As already discussed in section 3.2.1 of chapter 3, design can be too little constrained, but also over-constrained. Thereby, constraints can limit the design space to incorporate value. However, constraints can also give direction to find a solution (Stacey & Eckert, 2010). Methodological structures support the definition of constraints, which construct the design space. On its turn, the design space defines the space to incorporate value. Research into the relation between the methodological structure and the definition of the design space for integrated design is essential to understand the 'framing of the compatibility of multiple artifact frames' from a methodological perspective.

The semantics of integrated design, as described in chapter 2 and 3 only conceptually describe how to solve issues of integration. Therefore, chapters 4 and 5 are about the development of a methodological framework for integrated design. Chapter 4 will define the relation between the methodological structure and the design space for integrated design. The research in this chapter 4 focuses on the differences in framing the design space through methodological structures that are educated in different fields of design.

Reflection on the institutionalization of design is part of the broader description of design methodology. In this context, the description of the development of methodological structures will aim the understanding of the assumptions and modes of reasoning with respect to currently used methodological structures in different fields of design. Design methodology developed as an explicit field in modern science from the sixties of the twentieth century (Cross, 1993; Bayazit, 2004). In this chapter 4, the development from the early design sciences from the sixties till the current state of design methodology will be first part of research, to understand the foundations of currently used methodological structures. Thereafter, the question how these currently used methodological structures frame design in different fields of design will be at stake. In this context, the focus will be on an investigation of currently used design process models and design methods at different faculties of Delft University of Technology that are related to the design of an artifact. The investigated faculties are:

- Aerospace Engineering
- Architecture and the Built Environment

- Civil Engineering and Geosciences
- Industrial Design
- Mechanical Engineering

Chapter 4 is related to research question 3 and corresponding sub-questions 3.1 and 3.2. Research question 3 and sub-questions 3.1 and 3.2 are formulated as:

Research question 3:	What is the relation between the methodological structure and the definition of the design space for integrated design?
Sub-question 3.1:	How did methodological structures for design develop over time?
Sub-question 3.2:	How do currently used methodological structures frame design in different fields of design?

The aim of this chapter 4 is to define the relation between the methodological structure and the definition of the design space for integrated design, in order to understand the influence of the framing through methodological structures on the compatibility of multiple artifact frames.

Section 4.2 describes how methodological structures developed over time, related to sub-question 3.1. Thereafter, section 4.3 explains design process models and design methods per investigated faculty at Delft University of Technology that is related to the design of an artifact, related to sub-question 3.2. The concluding section 4.4 finally contains the conclusions with respect to research question 3 and sub-questions 3.1 and 3.2. This section 4.4 defines the relation between the methodological structure and the definition of the design space for integrated design.

4.2 The Development of Design Methodology

4.2.1 Cyclic Development

The structure of development of design methodology, as part of design sciences, can first of all be described as a cyclic process. Thomas Kuhn described this process more formally in his book 'The Structure of Scientific Revolutions' (Kuhn, 1962) in the context of the development of scientific ideas. Kuhn summarized this, to his idea, cyclic structured process in the so-called 'Kuhn Cycle'. The Kuhn Cycle, as presented in Figure 32, starts with an idea, initial research, a hypothesis, and certain prescience efforts. Prescience and Normal Science can cause Model Drift and Revolution, which eventually can result in a Paradigm Change as a new common state. The term 'Paradigm' is in this dissertation meant as defined by Kuhn (1962), when he describes a paradigm as an interrelated framework of scientific models and theories, which express a state of reality. A Paradigm Change is therewith a change of this interrelated framework and can span decades or even centuries. Although this possible long time span of change, Paradigm Change is preceded by clear milestones in many cases. Examples are the acceptance of Aristotle of the spherical shape of the Earth around 350 B.C., or the scientific statement of Nicolaus Copernicus about the heliocentric universe, which let to the so-called Copernican Revolution. The statement of Copernicus was later supported by observations of Kepler and Galileo (Kuhn, 1962).

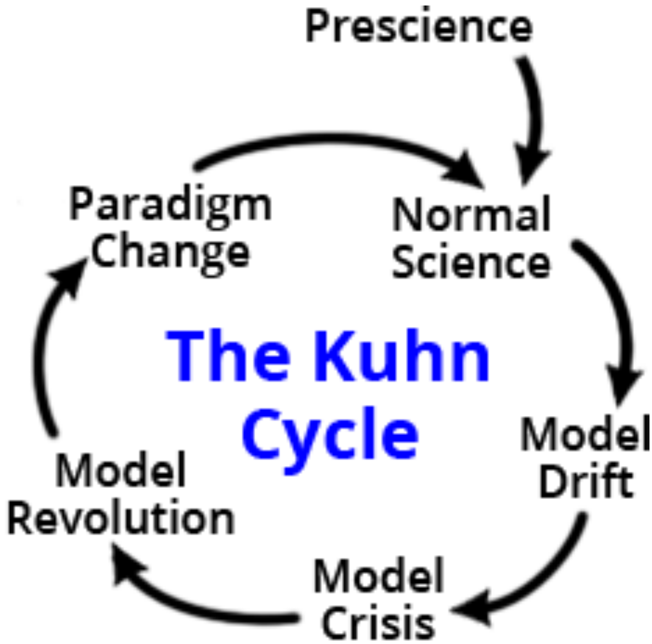
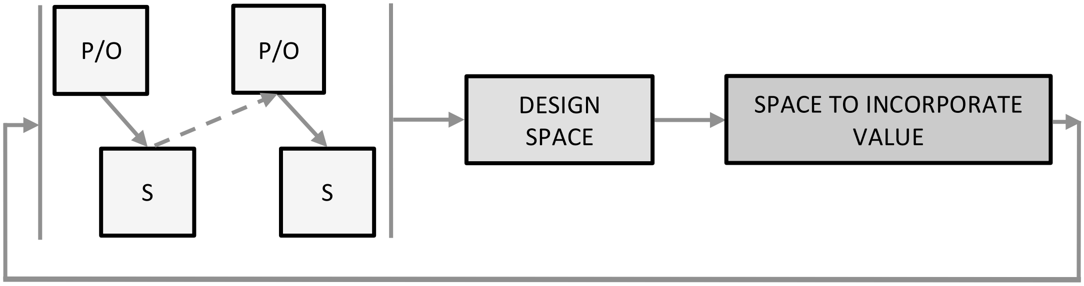


Figure 32 The Kuhn Cycle
Source: Kuhn (1962)

Increasing experience and knowledge through observations can result in new thoughts and insights. These new thoughts and insights can on their turn influence paradigms and institutions. North (1994) formulates institutional evolution as the interaction between institutions and organizations, where institutions form the rules of the game and organizations the agents who work with these rules. Examples of institutions are systems of language, money, law, restaurant etiquette, and systems of weight (Hodgsen, 2006). While all relating to another domain, these different institutions have in common that they constrain and enable behavior in a way that is predictable and stable to a certain extent. Hodgsen (2006) calls this 'the durability of institutions'. Predictable and stable institutional frameworks with corresponding methodologies can be 'durable', but also 'rigid'.

The cyclic process can on its turn also be identified for the scheme of the design space in relation to the space to incorporate value. When the space to incorporate value is not sufficient, the problem or opportunity space and the solution space should be (re)framed through (re)framing the constraints that form the different spaces. This cyclic process of design can be part of a single short term design loop in terms of validation and verification, but also develop over time, when for example additional forms of value are requested or interpretations of working principles to obtain value develop over time. Figure 33 schematizes the cyclic process of design. The feedback loop represents the reflection on the space to incorporate value on the short and the longer term.



P = PROBLEM SPACE
O = OPPORTUNITY SPACE
S = SOLUTION SPACE

Figure 33 Cyclic process of design with a feedback loop to reflect on the space to incorporate value

Figure 33 illustrates through the feedback loop that the reflection on the space to incorporate value is a main driver of iterative change. This iterative change can lead to a revision of the artifact design on the short and the longer term. On the short term, an artifact design can be adjusted before completion. However, reflection on the space to incorporate value can also lead to discussion and adjustment, even when the artifact design is already in operation. This raises the question if the design of an artifact can be declared as finished, or that the design process is an ongoing cyclic process of (re)framing. While an artifact is in operation, the design process can be stated as a continue ongoing cyclic process of (re)framing and reflection in order to maintain a desired space to incorporate value.

In a broader context, Prescience in the Kuhn Cycle can in design sciences be represented by the reflection on the space to incorporate value on the longer term. Design methodology will change over time when the space to incorporate value does not satisfy anymore.

4.2.2 Institutional Evolution

The general aim of design methodology as described in section 4.1 was added with the notion of a cyclic development of design methodology over time in section 4.2.1. From this point, the research will focus on how design methodology develops over time to its current state in academics. This will be executed to understand the foundations of current interpretations of design and corresponding methodological structures as applied at different faculties of Delft University of Technology.

When the institutional evolution can be seen as the interaction between institutions and organizations, institutional evolution is culturally dependent. This relation between cultural and institutional development also emerges in the structural roots of institutions, which are still influential today. Where Copernicus causes the Copernican Revolution with his statement about the heliocentric universe in his 'de revolutionibus obium coelestium' (on the revolutions of the celestial spheres) in 1543, it was exactly in this year that the Belgium doctor and anatomist, Andreas Vesalius published the first complete book about the human anatomy, 'de humani corporis fabrica libri septem'. Nowadays, these two influential publications are historically marked as the beginning of the evolution towards modern institutions. These institutions became more mature in the seventeenth century with a development to a, as called by Dijksterhuis (1950), 'mechanistic perspective of the world'. The increasing importance of observation and experiments as the fundament for scientific theory emerges rationalization as fundament for reasoning and institutional structure. This idea of reasoning was affirmed by Descartes' 'cogito ergo sum' in his 'Principles of Philosophy' in 1644, and Newton's laws of motion and universal gravitation in his 'Mathematical Principles of Natural Philosophy' in 1697. From that time, Newton's theory dominated scientists' view of the physical universe for the next three centuries. It was in these three centuries that most of today's common known institutional structures, like scientific models, were developed, based on this 'classical' mechanistic mode of thinking (Gershenson, 2007). Heylighen (1990a) set out some of the institutional assumptions of the 'classical thinking', formulated as 'determinism', 'dualism', 'correspondence theory of knowledge', 'rationality', and 'reductionism'. Heylighen (1989; 1990b) summarized these assumptions by the 'principle of distinction conservation' (Gershenson, 2007). Hertogh & Westerveld (2010) calls a similar mode the 'deterministic approach'.

Within the context of this 'classical thinking', empirical research became the major source of knowledge and scientific theory, expressed in one of the three main principles of Positivism, as described by Auguste Comte in his 'The Course in Positivist Philosophy' (1930-1942). Positivism stands for the idea that the objective reality can be found through empirical research and only this empirical research is an acceptable source for scientific theory (Schön, 1983). It is in this 'classical thinking mode' that many of the institutional structures are developed, which are still used today. Many examples can be found in the differentiated structures of political, academic, and corporate institutions. In the academic landscape, there is for instance a differentiation between general and technical universities. Within a technical university like Delft University of Technology several faculties are distinguished, for which Civil Engineering and Geosciences is one of them. Within the faculty of Civil Engineering and Geosciences their are again several departments, like Hydraulic Engineering, with tracks as river engineering, coastal engineering, hydraulic structures, etc. Hydraulic structures can on their turn again differentiated in examples like dikes, dunes, breakwaters, etc. It shows the highly specialized structure, which can be found in many organizations. The same holds for used methods and tools within organizations.

Although the development of specialized organizations and components over time, it does not guarantee the fit between the differentiated components in a larger context. This was the reason that Ludwig von Bertalanffy proposed the General Systems Theory in the 1940's as a reaction against separated design of system parts to emphasize the importance of system relations as part of a whole (Bertalanffy, 1968). Gielingh (2008) emphasizes additionally that the terms 'whole', 'system', 'sub-system' and 'part' does not have absolute meaning. 'Parts' can be 'wholes' and have to be defined on their own contextual level. This mode of thinking is called 'Systems Thinking' (Pourdehnad et al., 2011; Golden, 2013; Monat & Gannon, 2015). In this same mode of thinking, Herbert A. Simon tried to explicit the rationalization of designing in his publication 'The Sciences of the Artificial' in 1969, a fundamental publication on the systemization of engineering design. However, this interpretation of this systemization by Simon was still aligned over predefined interfaces with predefined interaction.

4.2.3 Engineering Design

Jones and Thornley (1963), Alexander (1964), Archer (1965) and Luckman (1967) wrote influential publication about design methodology in their efforts to develop a systemization of the design process. To systemize the design process, Jones and Thornley (1963) separated the design process in three phases, namely 'analysis', 'synthesis', and 'evaluation'. In line with the stage-model of Jones and Thornley, Archer (1965) explained the design process as a six-stage model: 'programming', 'data collection', 'analysis', 'synthesis', 'development' and 'communication'. In addition, Luckman (1967) emphasizes in his publication 'An Approach to the Management of Design' the analysis of information, requirements and constraints, in order to design possible solutions and reflect them on the requirements.

While the design models of Jones and Thornley (1963), Archer (1965) and Luckman (1967) differ in their final appearance, they have a common ground in their description of a sequential design process with comparable phases and defined design objectives. This perspective on design with defined sequential processing and with defined design objectives and constraints was and is indicated as 'engineering design'.

After the first fundamental contributions of Jones and Thornley, Archer and Luckman, models for 'engineering design' developed and increased in influence for industrial applications. Examples of influential models that were developed in this period are the models of Pahl and Beitz in 1984, the model of French in 1985, the model named 'Verein Deutscher Ingenieure' (VDI) in 1986, the model 'Workshop Design-Konstruktion (WDK) in 1989, Pugh in 1991, Roozenburg and Eekels in 1991, Ullman in 1992 and the model of Van den Kroonenberg and Siers in 1992. All these models are developed in order to aim reducing, as Jost (2004) calls, the 'external complexity', which is the complexity between different defined sub-systems. Pimmler and Eppinger (1994) refer to this paradigm in the context of 'Systems Engineering', which they describe along its two main purposes, defined as:

- Simplification: the assumption that smaller scale problems are less complex
- Speed: the assumption that sub-systems can be designed parallel, so-called 'concurrent engineering'

'Engineering design' was and is still mainly defined by the purposes as described by Pimmler and Eppinger (1994) from a perspective of 'Systems Engineering'. However, although 'Systems Engineering' became a successful methodological structure for many design cases, also discussion emerged from this explicit systemization of design.

4.2.4 A Broader Perspective on Methodological Structuring of Design

Section 4.2.3 described that some influential design researchers, such as Alexander (1964), Archer (1965), Jones (1966), Matchett (1968), Simon (1969) and Papanek (1971), defined design more from a problem-solving perspective, with a clear design objective, referring to a certain problem state. In contrast to this so-called 'engineering design', other researchers, like Reswick (1965), Page (1966) and Nelson and Stolterman (2002) emphasized the exploration of future possibilities and defined design as a matter of creation of new desired states instead of solving current problem states. Lawson and Dorst (2009) defined design as a more exploratory activity, but with a problem-solving objective. This difference in perspectives was already explained in chapter 2, with the construction of different futures towards a certain design perspective by De Jong (1992).

In addition to a differentiation in perspectives on the definition of design as a matter of act and purpose in relation to time, perspectives on the definition of design can also differ in terms of representation. Some design researchers define design in relation to a product or artifact (Buchanan, 2001; Love, 2002; Jones, 1970; Papanek, 1971; Alexander, 1964), while other design researchers define design more broadly as organizations, structures, or thoughts and actions (Jones, 1966; Hevner et al., 2004; Fuller, 1965; Heskett, 2005, Mau, 2007; Archer, 1979; Rand, 2001; Richardson, 1984). Finally, design can also be defined as a decision-making activity, like in the definition of Asimov (1962).

Although engineering design methods and corresponding applications increased attention and popularity in business and academics from the sixties of the twentieth century, it also raised the discussion about the systemization in designing. It were Jones (1977) and Alexander (1971) who rejected their earlier proposed systemization of designing by the conviction that designing cannot be fixed in a logical framework (De Vries et al., 1993). They changed from a 'Positivist' to a more 'Phenomenological' or 'Constructionist' epistemology (Dorst, 1997), which meant a change in the perspective on designing from respectively 'rationality through empiric' towards 'perception through experience' (Schön, 1983). In other words, next to the perspective on designing as an empirical objective based process, a perspective on designing as a human perception based process gained more influence. While the perspective on designing as an introspective effort created room for the typing of the 'design genius', its support in the research community was low (Dorst, 1997). This low support was a result of the lack of methodological explicitness.

It was Donald Schön who described designing as an introspective effort in a more explicit way in his book 'The Reflective Practitioner', which was published in 1983. Schön expressed designing along four phases, namely 'naming', 'framing', 'moving' and 'evaluating', which differed on three fundamental principles in relation to designing as a rational process of problem solving, as defined by Simon (1969) in his 'The Sciences of the Artificial'. The three fundamental principles of Schön show common ground in the interrelatedness of previously separated terms. Where rational problem solving assumed the separation of 'means' and 'ends', the separation of 'research' and 'practice', and the separation of 'knowing' and 'doing', Schön suggested designing as a process of interrelated activities. According to Schön, 'practice' is part of 'research', 'means' and 'ends' are interrelated, and 'knowing' and 'doing' strengthen each other in an iterative process (Schön, 1987).

The suggested design perspective of Schön (1983) was in addition to an attempt to explicit designing also a milestone in the search for new methodologies regarding designing. The search for new design methodologies was a result of the lack of success of rational problem solving methods since the 'first-generation' methods from the sixties of the twentieth century (Rittel, 1973). Especially for so-called earlier named 'wicked problems' (Rittel & Webber, 1973), the rational perspective was not satisfactory successful in participatory design processes. The participatory design processes required a more iterative design approach, as described Schön (1983). In 1987, Peter Rowe expressed a corresponding mode of thinking as 'Design Thinking' in his equally named publication (Rowe, 1987). 'Design Thinking' appeals to the interrelation between the definition of the problem and the solution, which are both subordinate to design. 'Design Thinking' introduced therewith a broader perspective on design in contrast to a more traditional perspective of finding solutions for a defined problem (Cross, 1991).

The diversification in perspectives resulted also in a diversification in the development of design methodologies from this period, although design methods related to 'Design Thinking' remained less explicit and less numerous than engineering design methods (Cross, 1993).

4.2.5 Modes of Reasoning in Design

In relation to the development of design methodologies, a discussion evolved about modes of reasoning with respect to design. The discussions about design methodologies and modes of reasoning cannot be seen uncoupled from each other and we therefore look closer to these different modes of reasoning in this paragraph. In this discussion, March (1976) differentiates the modes of reasoning for 'design' versus 'logic and science', and expresses the mode of reasoning for 'design' as 'productive' reasoning. The work of March was based on the pioneering work of Peirce about scientific modes of reasoning in the beginning of the twentieth century. The work of Peirce was later collected in edited publications such as Peirce (1992a), Peirce (1992b), and Peirce (1998). As Cross (1991) explains, Peirce broadened the reasoning domain with his so-called 'abductive' reasoning, besides 'deductive' and 'inductive' reasoning in a scientific context. Abductive reasoning is about hypothetical reasoning. While March's work was based on the work of Peirce, March described reasoning from a design perspective and preferred therefore 'productive' reasoning instead of 'abductive' reasoning. Later publications of Eekels (1983) and Zeng and Cheng (1991) suggested respectively 'recursive' and 'reductive' reasoning as more suitable expressions of 'design' reasoning. However, this research is not about the terminology regarding reasoning, but its relation regarding designing. In this context, it was Roozenburg (1993) who described designing in relation to 'abduction', based on the work of Peirce, but also incorporated the suggested differentiation in 'abduction' in 'explanatory abduction' and 'innovative abduction' by Habermas (1968). Dorst (2011) built in his work on Habermas' differentiation in 'abduction' and expresses the different modes of reasoning in designing as 'abduction 1' and 'abduction 2'. In the explanation of Dorst, 'abduction 1' is associated with 'conventional closed problem solving' and 'abduction 2' with 'open complex problem solving'. In later publications, Dorst translates 'abduction 1' in 'normal abduction', and 'abduction 2' in 'design abduction' (Dorst, 2015). In this dissertation, the terms 'abduction 1' and 'abduction 2' are used instead of 'normal abduction' and 'design abduction', because the earlier interpretation of design in chapter 2 can also incorporate 'normal abduction'. The use of 'normal abduction' and 'design abduction', while the interpretation of design in this research can also incorporate 'normal abduction', would be confusing. The schematic expressions of Dorst about this differentiation in 'abduction 1' and 'abduction 2' are presented in Figure 34.

The schemes of modes of reasoning in design by Dorst (2011) are defined in relation to the artifact frame. In chapter 2, the scheme of Dorst (2011) was used to explain the construction of the artifact frame and now modes of reasoning are explained in relation to the artifact frame. So, the construction of the artifact frame can be formed through different modes of reasoning in relation to design.

Equation by Dorst (2011) to schematize design reasoning:

Abduction 1:

Abduction 2:

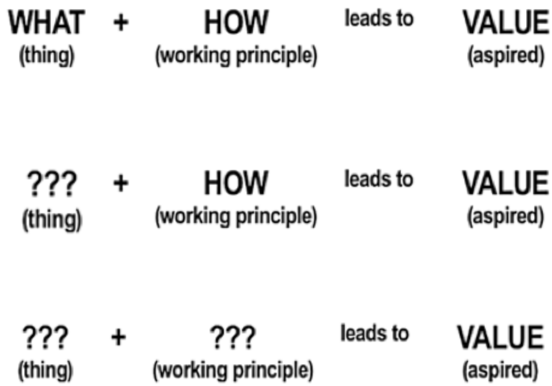


Figure 34 'Abduction 1' and 'abduction 2'
Source: Dorst (2011)

'Abduction 1' is about the hypothetical design process for which the aspired value and the working principle, to obtain the aspired value, are defined. The hypothetical design process is in that case related to the design of the 'thing'. 'Abduction 2' is about the hypothetical design process for which the aspired value is defined, but the working principle is subordinate to design. The hypothetical design process is related to the design of the 'thing' and the 'working principle'. The differentiation in 'abductive' reasoning also explains the difference in design, and definitions of design in different fields of design. Badke-Schaub et al. (2010) describe comparable observations in relation to different modes of reasoning in design, but do not use the term 'abductive' reasoning explicitly.

In reference to the scheme of design by Dorst (2011) can be said that some fields of design particularly focus on the design of the 'thing' with highly develop methods for constraining the design process. Other fields of design adopt a broader application of abductive reasoning in which the working principle is also subordinate to design. In addition, when the problem or opportunity space is ill-defined, the aspired value can also be subordinate to design.

The description of design reasoning by Dorst (2011) illustrates a distinctive representation of abductive reasoning. It differentiates design in design with a defined artifact frame, and design in which the definition of the artifact frame is part of the design itself. Design with a defined artifact frame is in this dissertation called 'defined abduction'. Design in which the definition of the artifact frame is part of the design itself is in this dissertation called 'frame abduction'. 'Frame abduction' can in addition to the framing and definition of the solution space also incorporate the framing and definition of the problem or opportunity space as part of design.

In section 4.3, the focus will be on this last notion of differences in reasoning in relation to framing of the artifact frame. For different faculties at Delft University of Technology, the design process and corresponding methods will be researched along the two introduced modes of reasoning: 'defined abduction' and 'frame abduction'. In practice, design reasoning cannot be completely linked to 'defined abduction' or 'frame abduction', and is the mode of reasoning a combination of the two. The differentiation in 'defined abduction' and 'frame abduction' is related to the discussion of, as Roozenburg and Cross (1991) describe as, the difference between the process of engineering design and the process of architectural/industrial design. In addition, Maier and Rechtin (2000) describe a similar differentiation as the 'Architecting-Engineering-Continuum', in which 'architecting' refers to 'frame abduction' and 'engineering' to 'defined abduction'. In line with this concept of a 'continuum' of Maier and Rechtin (2000), design will be reflected on a spectrum from 'defined abduction' to 'frame abduction' in this dissertation, which is illustrated in Figure 35. The spectrum of Figure 35 shows that in most cases design is a mix of 'defined abduction' and 'frame abduction'. However, except from the center of the spectrum, one of the modes of reasoning can be dominant in framing design.

Figure 35 Spectrum of abduction

The spectrum of abduction in Figure 35 refers to two main modes of reasoning in design that can be identified in the development of design methodology from the sixties of the twentieth century until today. These main modes of reasoning defined the identity of different schools of thought in design and shaped the education in different fields of design over time. An investigation of schools of thought in relation to the design of different artifacts, derived from corresponding methodological structures, will be executed for different faculties of Delft University of Technology. In section 4.3, the methodological structures for the design of an artifact at different faculties at Delft University of Technology will be reflected on the spectrum of abduction, which is presented in Figure 35.

4.3 Methodological Structures in Different Fields of Design

As elaborated in section 2.2.3, the artifact represents the intervention, as part of the concept of design. Examples of different types of artifacts are airplanes, buildings, or water barriers. The question is if these different types of artifacts also imply a difference in methodological structure for the design of these artifacts. In this context, sub-question 3.2 is formulated as: 'how do currently used methodological structures frame design in different fields of design?'.

The focus of this section 4.3 is on investigating the differences and similarities in methodological structures for the design of different artifacts. As part of this investigation, the elemental methodological structures for the design of different artifacts are researched for different fields of design. Research into different fields of design is executed along the structure of faculties at Delft University of Technology that are related to the design of an artifact. The researched faculties are:

- Aerospace Engineering
- Architecture and the Built Environment
- Civil Engineering and Geosciences
- Industrial Design
- Mechanical Engineering

The methodological structures for design at these faculties are researched along two main aspects, namely 'design process model(s)' and 'design method(s)'. These are the most explicit methodological structures that can be found, and also represent a basis for design education at different faculties. Design process models structure the design process and design methods can be used in different contexts within the design process. Appendix A gives an overview of the dominant design process models and design methods per investigated faculty.

In addition to an investigation of the design process model(s) and design method(s) per faculty, as methodological structures for the design of an artifact, the design methods are also related to different modes of reasoning, which were classified in section 4.2.5 as 'defined abduction' and 'frame abduction' and presented along the spectrum of abduction in Figure 35.

The investigation of the different modes of reasoning in design in section 4.2.5 resulted in the distinction in modes of reasoning with respect to the framing of the 'problem space' or 'opportunity space', and modes of reasoning with respect to the framing of the 'solution space'. Together, the problem or opportunity space and the solution space construct the design space.

Methodological structures frame the definition of the design space. For example, the design process can contain a phase that refers to the definition of the 'problem space'. In addition, the 'solution space' can be framed through standardized solutions and strict procedures that frame the solution space. Because the 'problem or opportunity space', and the 'solution space' are such distinctive terms and concepts in the scheme of the 'design space', the investigation of the modes of reasoning in design is also differentiated in respectively 'problem or opportunity space', and 'solution space'.

4.3.1 Aerospace Engineering

Design Process Model

Designing at the faculty of Aerospace Engineering is structured through the design process model of Pahl and Beitz (1984). This model consists of four phases, namely 'analysis', 'conceptual design', 'preliminary design' (materializing) and 'detailed design'. The model is a sequentially phased model with a funnel structure and feedback loops within every phase, as schematized in Figure 36.

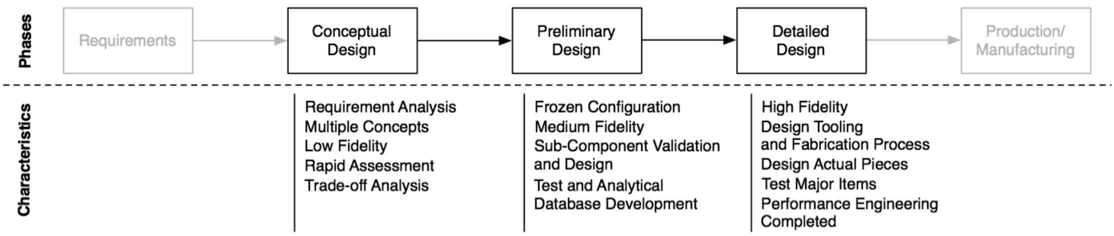


Figure 36 Design specification in the design process model of Pahl and Beitz
Source: Mavris & Pinon (2011)

A more elaborate scheme of the model of Pahl and Beitz (1984) is given in Figure 37. The scheme in Figure 37 also shows the feedback loops between different phases.

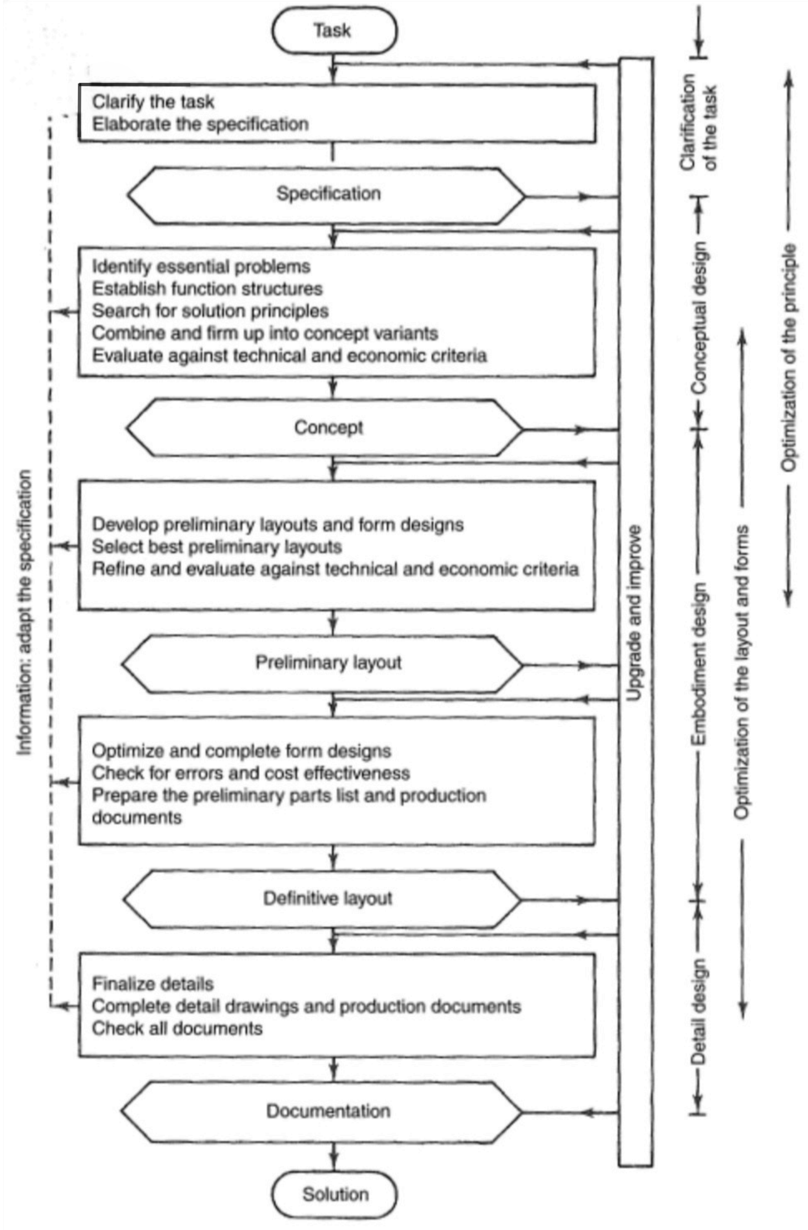


Figure 37 Elaborate design process model of Pahl and Beitz
Source: Pahl & Beitz (1984)

Mavris and Pinon (2011) researched the design process model in aircraft design and explained the interpretation of the design phases with explicit and specific design methods. From their analysis, Mavris and Pinon (2011) state that about 65 percent of the life-cycle cost of an aircraft is determined in the conceptual design phase. Because of the sensitivity in this phase in relation to the life-cycle cost of an aircraft, Mavris and Pinon (2011) emphasize the need for parametric formulation of the degrees of freedom for the design of an aircraft.

In addition, Mavris and Pinon (2011) emphasize the importance of parametric defined sub-systems when different disciplines are integrated to avoid re-iterating the design process until all requirements are met. The different disciplines, related to fields such as 'structures and weights', 'aerodynamics', and 'propulsion' have to be balanced in order to deliver an optimal defined performance. Therefore, integration with respect to the design of an aircraft is mainly about trade-offs between different defined disciplines and sub-systems in a parametric design process. A purpose of the parametric design process is to reduce uncertainty that is in the scope of the designer and corresponding stakeholders. Uncertainty in the design process is from that perspective considered as a possible threat instead of an opportunity. A similar perspective on the design process can be found for design at the faculty of Aerospace Engineering. Illustrative for the defined abductive reasoning in design at the faculty of Aerospace Engineering is the text on one of the lecture slides in the course 'Aerospace Design and Systems Engineering Elements I': 'design is all about making compromises', and 'you can only make one thing best at a time'. It emphasizes that it is important to have clear objectives, such that the design drivers can be selected (for example 'range', 'payload', 'speed', 'weight', and 'cost') (Vos et al., May 18, 2016). The design reasoning behind 'Systems Engineering' plays a crucial role in the structuring of design at the faculty of Aerospace Engineering.

In addition can be said that the conceptual design phase for design at Aerospace Engineering is structured by principles of Axiomatic Design. Axiomatic Design was introduced by professor Nam P. Suh in the eighties of the twentieth century. As the core of principles of Axiomatic Design, Suh (1990; 2001) formulated two axioms, namely:

- Independence axiom: an optimal design maintains functional independent requirements
- Information axiom: an optimal design minimizes information content

The independence axiom is satisfied when 'each parameter affects one functional requirement only'. When 'a design parameter influences more than one functional requirement', the independence axiom is not satisfied (Benavides, 2012). As described in Benavides (2012), the axiomatic design process is sequentially structured in respectively 'customer needs', 'functional requirements', 'design parameters', and 'process variables'. In accordance with principles of Axiomatic Design can be said that functional modules that are related to corresponding design aspects and disciplines define the solution space for design in the conceptual phase at Aerospace Engineering.

In the preliminary design phase, the focus is mainly on the specification of the interactions between different sub-systems or elements of a selected concept. Traditionally, aspects such as 'aerodynamics' and 'structural efficiently' are tightly coupled and the aircraft design process is driven by this dominant relation of these aspects. Therefore, the introduction of other aspects, such as maintainability and sustainability, can also transform the focus of the traditional design process (Mavris and Pinon, 2011). The detailed design phase is about the detailed specification of design and manufacturing, in which uncertainty that is in the scope of the designer is further reduced. The interactions between different sub-systems or elements are in the detailed design phase ideally completely defined.

Design Methods

As described, 'Axiomatic Design Axioms' frame the problem and opportunity space in the design process at Aerospace Engineering. Therefore, 'Axiomatic Design Axioms' are methodological structuring principles, which are dominated by 'defined abduction'. From these principles, methods such as 'Function Analysis' and 'Process Analysis', are developed. For the evaluation of a design, 'Multiple Attribute Decision Making' (MADM) can be used as a mathematical method to solve complex decision-making problems with multiple attributes (Mavris and Pinon, 2011). In addition to MADM methods, 'Multidisciplinary Analysis and Design Optimization' (MDA/ MDO) can be used during designing to address design conflicts, solve these conflicts and optimize structures. MDA/ MDO methods are used in all design phases for this purpose. MADM and MDA/ MDO methods are related to 'defined abduction', because it allows reasoning within a defined frame for design.

The reflection of the different investigated methods for framing of the problem or opportunity space on the spectrum of abduction gives an overview of the dominant modes of reasoning with respect to the different methods, as presented in Figure 38. However, the positions of the different investigated methods on the spectrum of abduction is an indication with respect to its overall dominant mode of reasoning, while the absolute positions can be discussed. In addition, the distances between the positions of different methods are meant position-wise and not scale-wise. Also the distances between the positions of different methods are subjective to indication and can be discussed. However, for an overall analysis and indication of the dominant modes of reasoning for design at Aerospace Engineering, the spectrum of abduction and corresponding indication of the methodological structures is suitable for the research as presented in this dissertation.

With respect to framing of the solution space, different methods apply. A method that can be applied during the conceptual design phase is for example 'Parametric Design Formulation'. 'Parametric Design Formulation' can support the design of system integration when multiple combinations of parameters are investigated to lead to a final conceptual design. The design methods in this phase of the design show already a high level of systemization of the design process in Aerospace Engineering and are related to 'defined abduction'. Working principles are defined and the design alternatives are found within the boundaries of the defined working principles.

An additional design method at Aerospace Engineering that illustrates the mode of thinking in the design process is the 'Reduced-Order Model' (ROM). The 'Reduced-Order Model' supports reducing complexity to levels that are suitable for parametric modeling, and is methodologically related to 'defined abduction'. 'Funnel Design' is the methodological structure of increasing detailed focus and freezing design decisions in sequential design phases, and is also related to 'defined abduction' (Mavris and Pinon, 2011). The design process model and design methods frame the design process of defining the problem, opportunity, and solution space, in order to define the design space. The design process of Aerospace Engineering has a dominant focus on a defined problem, opportunity, and solution space. Decreasing the design space is in that context beneficial for decreasing uncertainty.

An overview of the dominant modes of reasoning with respect to different methods that frame the problem or opportunity space and solution space are given in respectively Figure 38 and Figure 39. Additional design methods that are commonly used at the faculty of Aerospace Engineering are given in Appendix A.1.

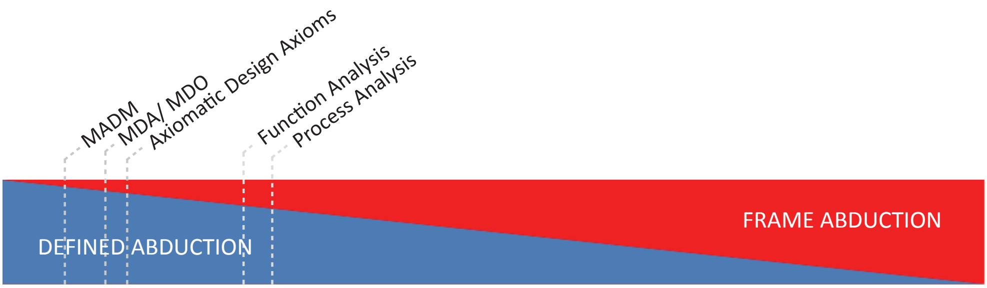


Figure 38 Modes of reasoning in design methods for framing the problem or opportunity space at faculty of Aerospace Engineering

Figure 39 Modes of reasoning in design methods for framing the solution space at faculty of Aerospace Engineering

4.3.2 Architecture and the Built Environment

Design Process Model and Design Methods

Although, designing at the faculty of Architecture and the Built Environment is developed along a certain mode of reasoning, this mode of reasoning is not always explicit in specific methodological structures. In addition, the design process model and design methods are interwoven methodological structures in many cases.

Although the methodological structures are not always explicitly defined for design at the faculty of Architecture and the Built Environment, the ideas of Schön (1983) about designing can be observed in architectural designing. Schön (1983) described design as an introspective process and defined four design phases in this context, for which their relations are schematically presented in Figure 40.

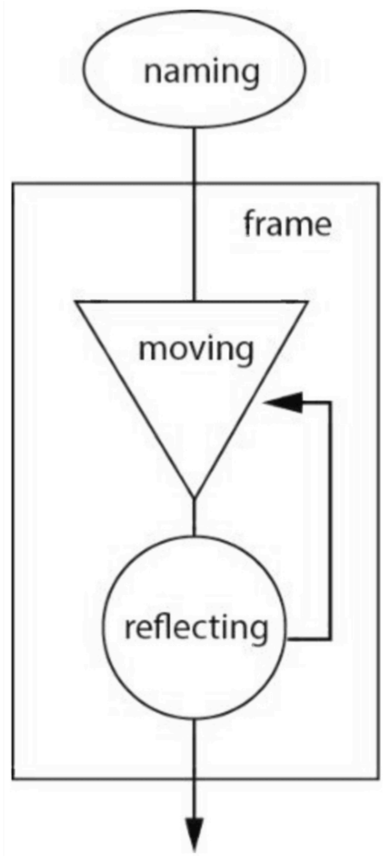


Figure 40 Design process model of Schön
Source: Valkenburg & Dorst (1998)

As Valkenburg and Dorst (1998) describe in reflection on the model of Schön (1983), 'naming' is about the identification of the relevant aspects of the design activity. 'Framing' is described as the definition of the context for further activities, as part of the design activity, and a focus to hold on during the design process. In addition, 'moving' is related to generating ideas, and finally, 'reflecting' represents the process of iteration in design. Schön (1983) describes each move in architectural designing as a local experiment, which contributes to the global experiment of reframing the problem. Overall, 'naming', 'framing', 'moving', and 'reflecting', also show a process of specification and order of sequence of design.

The design process model that is described by Leupen et al. (2013) is in its structure comparable with the structure of the design process model of Schön (1983). Figure 41 shows the scheme of the design process model as described by Leupen et al. (2013).

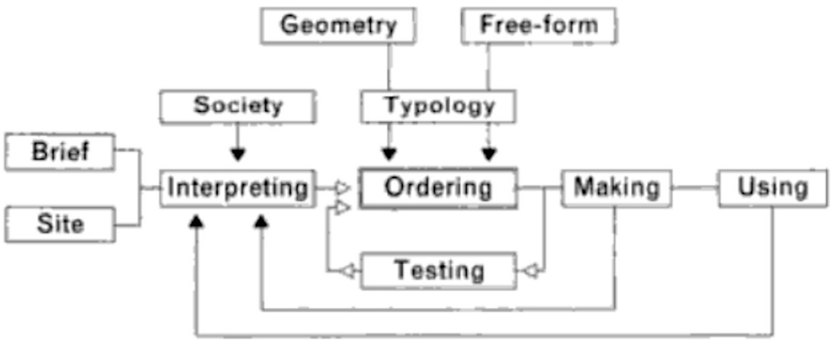


Figure 41 Elements in the architectural design process as described by Leupen et al. (2013)
Source: Leupen et al. (2013)

The elements 'Brief' and 'Site' refer to the program and location, and are part of the context of the design. The program is about the requirements and cultural or conventional rules. The location is the most physical part of the context. Additional elements of the context in relation to the location can be the origin of the location, the background, and the societal processes in which the design takes place.

From the researched context, the designer continues with the 'Interpreting' of this context, which means an interpretation of the different forms of value and weights regarding the design requirements and wishes.

The 'Typology' refers to known or newly developed types of for example stairs, windows, doors, auditoria, building forms, dwellings and urban layouts, as Leupen et al. (2013) describe.

The interpretation of the designer in combination with the development of typologies will lead to 'Ordering', which forms the connection between the interpretation of the designer and different typologies. This process can also be described as the composition of the design.

The 'Testing' refers to a check of the design in relation to the earlier stated requirements. Therefore, testing is part of the reflection of the designer. Also the 'Making' and 'Using' are part of this reflection, and give input to the interpretation of design case by the designer. Leupen et al. (2013) describe the design process as a deepening iterative process that is partly cyclic and partly developing in different directions.

Through the whole process, the analysis and design is given shape through drawing and modeling, which are essential elements in the architectural design process.

The description of Leupen et al. (2013) for the design process is used at the faculty of Architecture and the Built Environment. Although the different elements increase the understanding of the methodological structures at the faculty of Architecture and the Built Environment, the different elements do not represent explicit methodological structures. However, the description of the different elements by Leupen et al. (2013) gives sufficient input to describe the different elements of the design process at the faculty of Architecture and the Built Environment in relation to the spectrum of abduction of Figure 35. The different elements that are derived from the description of Leupen et al. (2013) are:

- Context
  The context is formed by the requirements, wishes, and research into origins, background, and society. What is taken into account for the analysis of the context is partly imposed by the requirements, but is also a result of for example the experience and choices of the designer. Therefore, the analysis of the context can is related to reasoning with a defined frame, in the form of the requirements in most cases, but also reasoning in which the definition of the frame is part of the design itself. The context, as a part of the design process, can therefore in its description be typed as a mix between 'defined abduction' and 'frame abduction'

- Interpretation
  The interpretation of the context can be bounded by the experience and desires of the designer, but the frame of interpretation is not methodologically defined on beforehand. The reasoning in the interpretation part can therefore predominantly be described by 'frame abduction'

- Typology
  Leupen et al. (2013) describe in relation to the typology two directions, namely typologies that are known by the designer as a sort of library of options, and typologies that are newly developed by the designer. Applying known typologies seems appealing to a morphological systematic approach. However, the application of the known typologies in the researched context can be unique. Known typologies then function as a source of inspiration for the designer. The boundaries between applying known typologies and developing new typologies fade in that situation

- Ordering and Composition
  In ordering and composition, the interpretation of the context and the typology come together. The designer literally embodies this relation. Therewith, the description of design as an introspective process by Schön (1983) can also be observed in the description of Leupen et al. (2013). The definition of the frame for design is part of the design itself, and is therefore the predominant mode of reasoning in ordering and composition related to 'frame abduction'

- Reflection
  The reflection is mainly related to the program as defined from studying the context and is short cyclic of character. The designer develops the design through short iterative cycles. Therefore, it can be stated that the reasoning in the reflection part refers to the program, but iterations can deepen the design and add to the development of the interpretation of the designer. The reflection is therewith a mix between 'defined abduction' and 'frame abduction'

- Sketching and Modeling
  Sketching and modeling are used by the designer through the whole design process. It forms a way to give expression to the thoughts of the designer and supports development of typologies, concepts, and reflection. Jack Howe, an engineering designer, stated in an interview that: 'I draw something, even if it is 'potty', I draw it. The act of drawing seems to clarify my thoughts' (Cross, 1990). Sketching and modeling are bounded by the skills and means of the designer to draw and model, but can also add to the framing of the design itself. Therefore, sketching and modeling are not only an explicit expressive part of the design process, but also add to the definition of the frame, which refers to 'frame abduction'

The different elements of the design process, as described by Leupen et al. (2013), show a sequential order of phases during the design process. This is apart from 'Sketching and Modeling' that is applied through the whole design process. However, the different elements are also characterized by a predominant mode of reasoning in which the frame for design is part of the design itself, referring to 'frame abduction'. Dependent of the context of the design, the defined design objective, as constructed by the different defined futures, can be related to 'problem-solving', 'discovery-driven', or 'creation-driven'. In Appendix A.2, the relation between the design phases of Schön (1983) and the elements 'context', 'interpretation', 'typology', 'ordering and composition', 'reflection', and 'sketching and modeling' is presented. In addition, a differentiation of these methodological elements as applied at the faculty of Architecture and the Built Environment is given to get an impression of what the different elements comprehend in terms of methodological structure. Because of the implicit character of the design process at the faculty of Architecture and the Built Environment, the described main elements are related to the spectrum of abduction.

Regarding the spectrum of abduction, 'context' and 'reflection' can be indicated as the elements in the design process, which are related to the definition and discussion of the problem or opportunity space. The reasoning in the elements 'context' and 'reflection' is a mix between 'defined abduction' and 'frame abduction', as illustrated in Figure 42. In Figure 42, 'sketching and modeling' is given a position on the spectrum of abduction as well, because this also frames the problem or opportunity space. In addition, 'sketching and modeling' and 'reflection' are elements that can also be presented in relation to the spectrum of abduction for the definition and discussion of the solution space, as illustrated in Figure 43. 'Sketching and modeling' and 'reflection' can in that context be placed on the same position on the spectrum of abduction, because they contain the same mix of 'defined abduction' and 'frame abduction'.

In addition, 'interpretation', 'typology', and 'ordering and composition' are methodological elements that are also related to the framing of the solution space. 'Interpretation' seems an introspective act and the predominant mode of reasoning is 'frame abduction'. 'Typology' refers to a set of known options or serves as inspiration for the design and development of new typologies. Therefore, 'typology' shows a mix of 'defined abduction' and 'frame abduction'. Finally, 'ordering an composition' is the element in which 'interpretation' and 'typology' comes together. The reasoning in the element 'ordering and composition' is predominantly related to 'frame abduction', as presented in the spectrum of Figure 43.

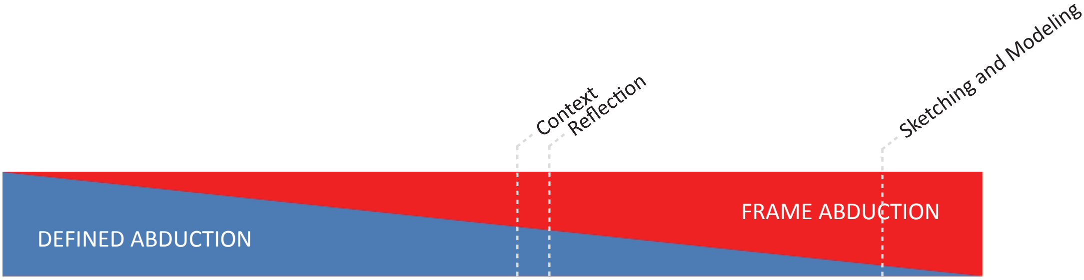


Figure 42 Modes of reasoning in design methods for framing the problem or opportunity space at faculty of Architecture and the Built Environment

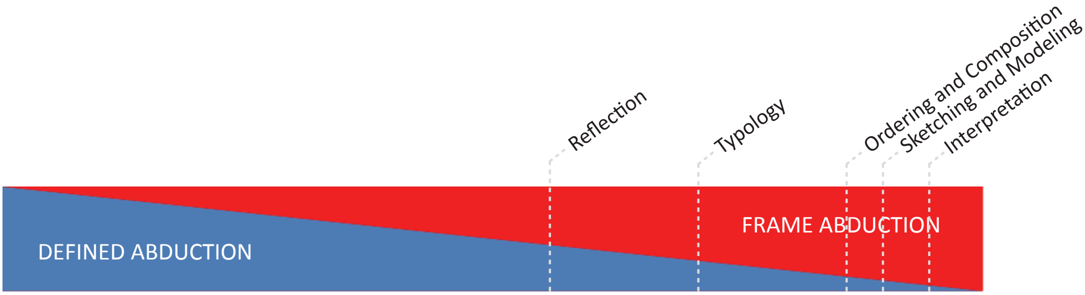


Figure 43 Modes of reasoning in design methods for framing the solution space at faculty of Architecture and the Built Environment

4.3.3 Civil Engineering and Geosciences

Design Process Model

At the faculty of Civil Engineering and Geosciences, the design process model of Roozenburg and Eekels (1995) is the main model for structuring the design process. The model of Roozenburg and Eekels (1995) is based on their research into the design models of in particular Pahl and Beitz, VDI, WDK, French, Pugh, Ullman and Van den Kroonenberg and Siers. Besides, the phase structure of the design process according to Roozenburg and Eekels looks quite similar to the phase structure of the models of Jones and Thornley (1963), Archer (1965) and Luckman (1967). The main phases of the design process model of Roozenburg and Eekels are 'analysis', 'synthesis', 'simulation', and 'evaluation'. The interpretation of the design process model of Roozenburg and Eekels illustrates the mode of thinking and reasoning. The sequential structure of the design process and focus on well-defined problems characterizes the framing of the problem and opportunity space for design at the faculty of Civil Engineering and Geosciences. In addition, the reasoning behind 'Systems Engineering' increasingly shapes designing at the faculty of Civil Engineering and Geosciences.

Several design methods, as researched by Beheshti (1999), provide insight in the mode of thinking and reasoning in civil engineering design. A schematic overview of the cyclic phasing model of Roozenburg and Eekels is given in Figure 44.

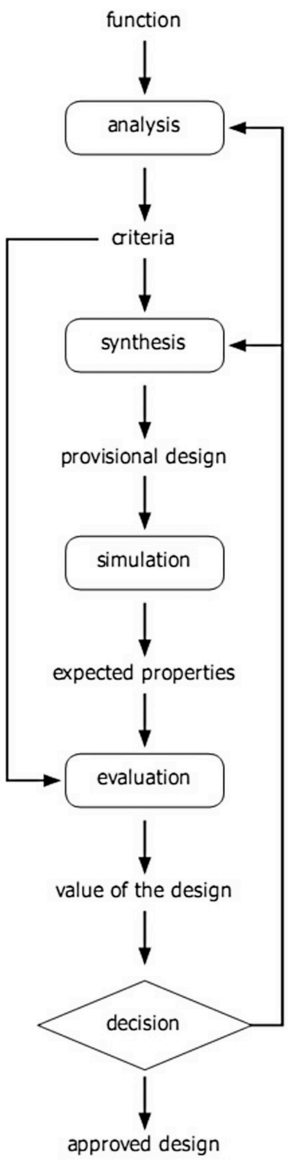


Figure 44 Design process model Roozenburg and Eekels
Source: Roozenburg & Eekels (1995)

Design Methods

Clustered to the elements in the equation of Dorst (2011), the definition of the problem or opportunity space is formed by the design methods in the analysis phase, and evaluated on their incorporated value in the evaluation phase. The analysis phase incorporates methods like 'Screen Analysis', 'Potential Surface Analysis', 'Stakeholder Analysis', 'Process Analysis' and 'Function Analysis' (Beheshti, 1999). The methods used in the analysis phase give an indication of the definition of the problem and input for criteria in the evaluation phase. In the mentioned methods, the definition of the problem is formed through a broader analysis than only the artifact itself. For example, the 'Stakeholder Analysis' and 'Potential Surface Analysis' also incorporate contextual aspects. The 'Process Analysis' and 'Function Analysis' are however more referring to the design process in relation to the artifact and can be both related to a more defined form of abduction or be subordinate to design themselves.

In the evaluation phase, methods like the 'Qualitative Permutation Method', 'Quantitative Concordance Method' and 'EVAMIX Method' are used frequently as interpretations of multi criteria evaluation (Beheshti, 1999). These methods are evaluating design alternatives, but as an evaluation between trade-offs, in which the working principles of the alternatives can differ. In addition, design requirements related to quantitative structural performance are incorporated through application of Euro-codes. Euro-codes are performance requirements as set by European law and are binding. In addition, the application of Euro-codes frame the design process towards tested solutions as part of for example Morphological Methods. Therewith, the abductive reasoning is also defined in that sense.

For the evaluation of design alternatives, Multi-Criteria Evaluation reasons from a defined set of criteria that can be imposed. However, Multi-Criteria Evaluation also incorporates room for defining criteria that are subordinate to design, and therewith the valuation of design alternatives regarding these criteria. Therefore, Multi-Criteria Evaluation cannot be attributed to only 'defined abduction' or only 'frame abduction', but shows elements of both.

The total spectrum of methods that frame the problem or opportunity space in relation to 'defined abduction' and 'frame abduction' is presented in Figure 45. Design methods that are related to the framing of the problem or opportunity space show the incorporation of the context, which seems also logic when taking into account the scale and location bounded character of designed artifacts at Civil Engineering and Geosciences. The attempt to reflect for example stakeholder desires from the Stakeholder Analysis into the set of criteria for the Multi Criteria Evaluation shows that the definition of the frame for design is partly subordinate to design.

The framing of the solution space relates to methods such as the 'Combinative Method', the 'Morphological Method', 'AIDA Method' (Analysis of Interconnected Design Areas), 'Coding Method', 'Brainstorming' and 'Design and Decision-Making Trees' (Beheshti, 1999). Except from 'Brainstorming' as a more generic method for synthesizing, these methods with respect to framing of the solution space have a morphological character with a focus on decomposition of the artifact. The methods that frame the solution space are therefore more related to 'defined abduction' at Civil Engineering and Geosciences, as presented in Figure 46. An overview of design methods that are commonly used at the faculty of Civil Engineering and Geosciences in relation to the different phases of the design process is given in Appendix A.3.

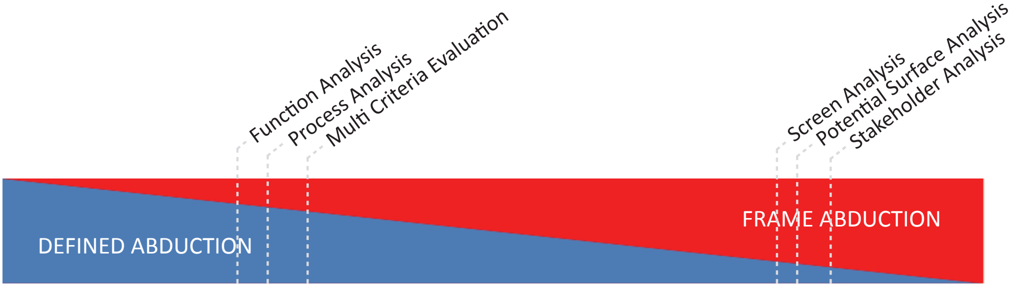


Figure 45 Modes of reasoning in design methods for framing the problem or opportunity space at faculty of Civil Engineering and Geosciences

Figure 46 Modes of reasoning in design methods for framing the solution space at faculty of Civil Engineering and Geosciences

4.3.4 Industrial Design

Design Process Model(s)

The dominant design process model at Industrial Design is the design process model that is also used at Civil Engineering and Geosciences, namely the model of Roozenburg and Eekels (1995), see Figure 44. However, also other design process models increased in influence in relation to the model of Roozenburg and Eekels over the last years. The design process models that are used at the faculty of Industrial Design are described in the Delft Design Guide by Van Boeijen et al. (2013) and summarized below. The different design process models, or elements of different models, can be used separately or intertwined in its relevance to different design cases.

- Reasoning in Design
- Basic Design Cycle
- Product Innovation Process - 1
- Product Innovation Process - 2
- Creative Problem Solving
- Vision in Product Design (ViP)
- Design for Emotion
- Brand Driven Innovation
- Service Design
- Cradle to Cradle
- Base of the Pyramid (BoP) and Emerging Markets

The design process models 'Product Innovation Process - 2' and 'Vision in Product Design (ViP)' will be elaborated a bit more, because these models increased in influence, in addition to the dominant structuring of the design process by Roozenburg and Eekels in their so-called Basic Design Cycle.

The 'Product Innovation Process - 2' is a model, which is related to the design of the business development of a product (Buijs, 2003). The model consists of five phases, namely: 'product use', 'strategy formulation', 'design brief formulation', 'development', and 'market introduction', schematically presented in Figure 47. The sequential phases are cyclic and the 'product use' stage can therefore be defined as the final or the first stage of the product innovation process. In each case, the analysis of the 'product use' directs the 'strategy formulation' and further 'design brief formulation', 'development', and 'market introduction' of the intended product.

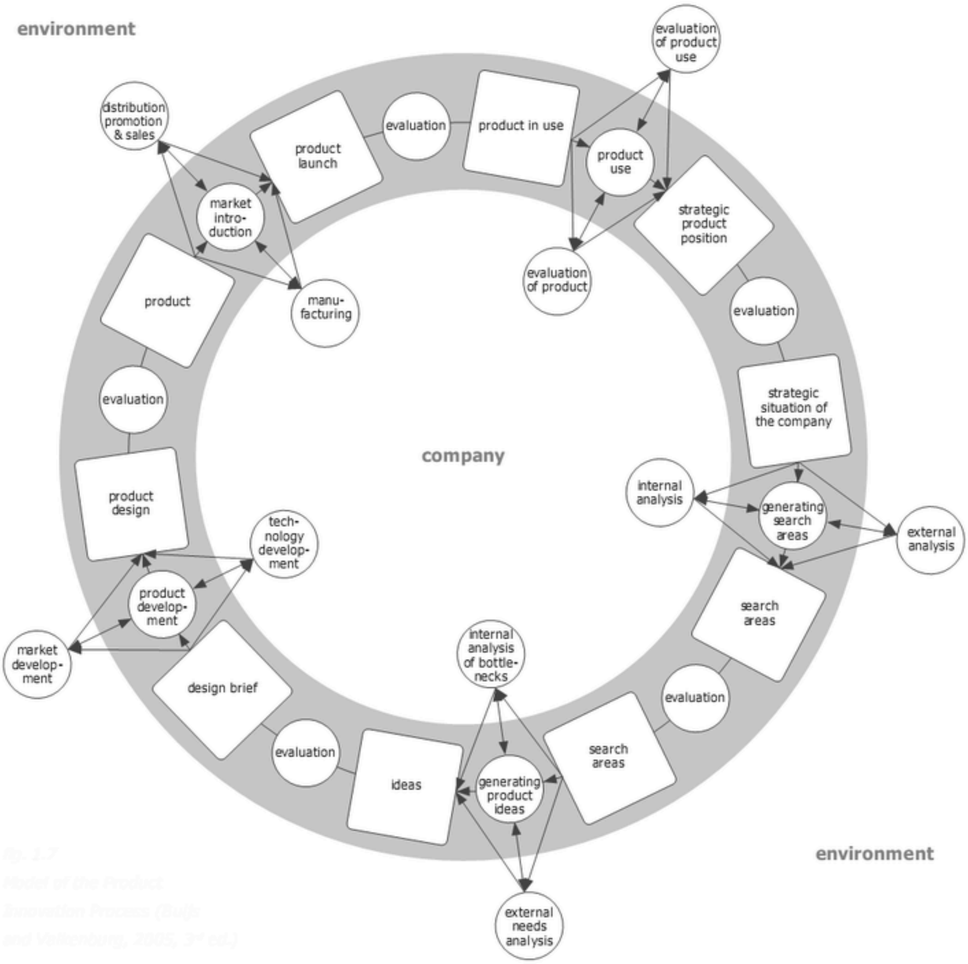


Figure 47 Design process model Buijs
Source: Buijs & Valkenburg (2005)

'Vision in Product Design (ViP)' is a design model, in which two main phases can be distinguished, a 'deconstruction' and a 'designing' phase, schematized in Figure 48. The 'deconstruction' phase reasons from the old product to the old interaction and past context and can give the insights for the designer to design from this understanding sequentially the future context, the new interaction and the new product. The formulation of the future context could also be expressed as the vision in relation to the product design from the understanding of the context. Because the new product is designed in reference to a vision or future context, the assumption in this design model is that the creativity leap could be larger than product design with requirements and boundary conditions as set in advance (Hekkert & van Dijk, 2011).

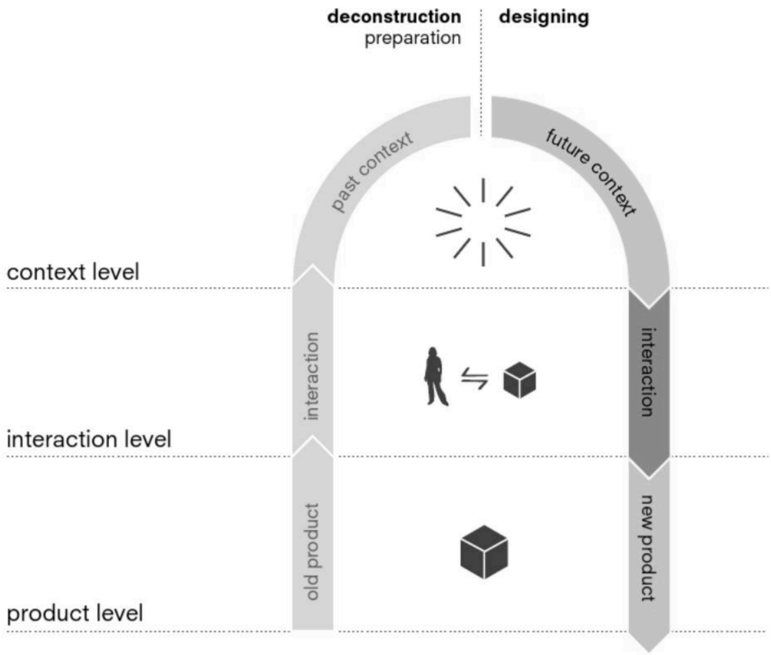


Figure 48 Design process model Hekkert and Van Dijk
Source: Hekkert & Van Dijk (2011)

The increasingly influential design models of Buijs (2003) and Hekkert and Van Dijk (2011) have in common that they both explicitly focus on the understanding of the old product in its context as the major driver for the development of a new product and related business. This is different from the design model of Roozenburg and Eekels (1995), in which the definition of requirements and boundary conditions are approached in relation to a single design cycle, instead of multiple design cycles over several product life cycles. However, the observed behavior of an old product can serve as information for the definition of requirements of a new product. The design models of Buijs and Hekkert and Van Dijk identify methodologically seen more contextual elements in designing than the design process model of Roozenburg and Eekels. Although, the models of Buijs and Hekkert and Van Dijk are increasingly influential in relation to the model of Roozenburg and Eekels, the structuring of design methods as interpretations of the design process model can still be referred to the structuring of the design process as suggested by Roozenburg and Eekels, which was presented in Figure 44. The dominant design process models of Industrial Design and Civil Engineering and Geosciences are therewith the same. However, the design methods that can be applied in the design phases differ for the two faculties. Therewith, the definition of the design space through methodological structures is different.

Design Methods

Design methods that are educated at the faculty of Industrial Design, and which can be used in different design process phases, are described by Van Boeijen et al. (2013) in the Delft Design Guide. Most of the design methods that are presented in the Delft Design Guide are related to a particular aspect of the design process. The designer can choose which design methods can be helpful and applicable in a particular design challenge. The number of presented design methods in de Delft Design Guide is too large to explain all of them in this dissertation, but a couple of design methods will be explained to give more insight in the modes of reasoning in design. These design methods are characteristic and frequently used and illustrate the diversity in design methods as used at the faculty of Industrial Design. An overview of the design methods that are commonly used at the faculty of Industrial Design is given in Appendix A.4.

In the analysis phase, different aspects of designing are researched through different methods. 'Personas' is for example a method to investigate the archetypal representations of intended users. In addition, 'Storyboard' is used to analyze the lifecycle of a product, and the 'Business Model Canvas' of Osterwalder and Pigneur goes into the business model of the product. The reasoning in the analysis phase can be interpreted from several perspectives as the combination of 'defined abduction' and 'frame abduction', which frames the problem or opportunity space. The 'Function Analysis' is an example of a possible design method that is more referring to the artifact, while 'Personas' is referring to the 'aspired value' of the intended users. Another example of a design method with respect to framing of the problem space is called 'WWWWWH', which stands for 'Who', 'What', 'Where', 'When', 'Why' and 'How', and serves as a checklist for defining the problem. This method is mainly used to structure the analysis of the design problem and obtain the necessary information from for example stakeholders in the context of the definition of the problem. Two design methods from the evaluation phase are 'Interaction Prototyping and Evaluation', which is frequently used in combination with other methods, like 'Storyboard', and 'Weighted Objectives'. These methods also refer to different modes of reasoning, because 'Prototyping and Evaluation' and 'Weighted Objectives' can be related to 'defined abduction', while 'Storyboard' can be related to 'frame abduction'.

The Delft Design Guide also contains so-called 'Discovery Methods', which can be used in all phases of the design process and more strategically oriented regarding the specific product markets. Examples of 'Discovery Methods' are 'Context Mapping', 'Mind Map', 'Strategy Wheel', 'Trend Analysis', 'SWOT Analysis' and 'Perceptual Map'. The Delft Design Guide contains multiple design methods regarding framing of the problem or opportunity space. These design methods differentiate in their mode of reasoning on the spectrum of abduction, as presented in Figure 49. The choice of the designer to apply certain design methods defines the mode of reasoning with respect to the framing of the problem or opportunity space. As Figure 49 shows, the mode of reasoning with respect to the framing of the problem or opportunity space can be predominantly 'defined abduction', 'frame abduction', or a combination of both.

With respect to the framing of the solution space, a similar differentiation in modes of reasoning in design methods can be observed. For example, the 'Fish Trap Model' is a method to structure the search of form and material of the product, and is related to 'defined abduction'. The same holds for the mode of reasoning in the 'Morphological Method', which can be used to develop a design from known working principles. On the other hand, the design method 'Synectics' is also a synthesizing method, but is related to 'frame abduction'. The aim of 'Synectics' is to broaden the mindset of the designers, and can be used in teams or individually. An overview of the reflection of the discussed design methods for framing of the solution space, presented on the abduction spectrum, is given in Figure 50. The distribution of design methods along the spectrum of abduction shows that design methods for framing the solution space are related to both 'defined abduction' and 'frame abduction'.

Although the design process at the faculty of Industrial Design can be structured along for example the design process model of Roozenburg and Eekels, the investigation of the design methods from the Delft Design Guide show that the framing of the problem or opportunity, and the solution space, is dependent of the applied design methods by the designer. Therewith, the mode of reasoning is dependent of the applied design methods and can range from 'defined abduction' to 'frame abduction'.

The faculty of Civil Engineering and Geosciences and the faculty of Industrial Design both apply the design process model of Roozenburg and Eekels. However, the investigation of the design methods that are used at the faculty of Industrial Design shows that the modes of reasoning can differ within and between different phases of the design process. Design at the faculty of Industrial Design therefore incorporates more opportunities for 'frame abduction' than design at the faculty of Civil Engineering and Geosciences. In addition, at the faculty of Industrial Design, the designer has also the option to apply the design process models of Buijs, or Hekkert and Van Dijk, which give more opportunities to frame the design process. The combination of the design process models and the design methods shows that design at the faculty of Industrial Design can be methodologically structured and framed in diverse ways, and that a designer can choose which methodological structures to apply.

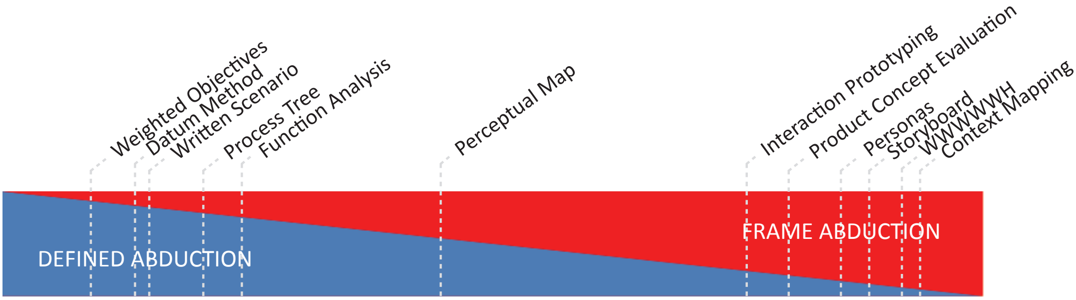


Figure 49 Modes of reasoning in design methods for framing the problem or opportunity space at faculty of Industrial Design

Figure 50 Modes of reasoning in design methods for framing the solution space at faculty of Industrial Design

4.3.5 Mechanical Engineering

Design Process Model

The dominant design process model at the faculty of Mechanical Engineering changed from the design process model of Kroonenberg and Siers (1992) to the model of Pahl and Beitz (1984). The design process model of Kroonenberg and Siers (1992) contains of three main phases and several sub-phases. The particular characteristic of the model of Kroonenberg and Siers is the interrelation between the 'design of the object or thing' and the 'design of the manufacturing'. Kroonenberg and Siers suggested their model after studying the design models of Hansen, Krick, Asimov, Rodenacker, Matousek, Roth, Koller and VDI (Zeiler & Quanjel, 2008). While the design model is presented differently for these models, Kroonenberg and Siers (1992) found that they are all based on three main phases with similar characteristics, as schematized in Figure 51.

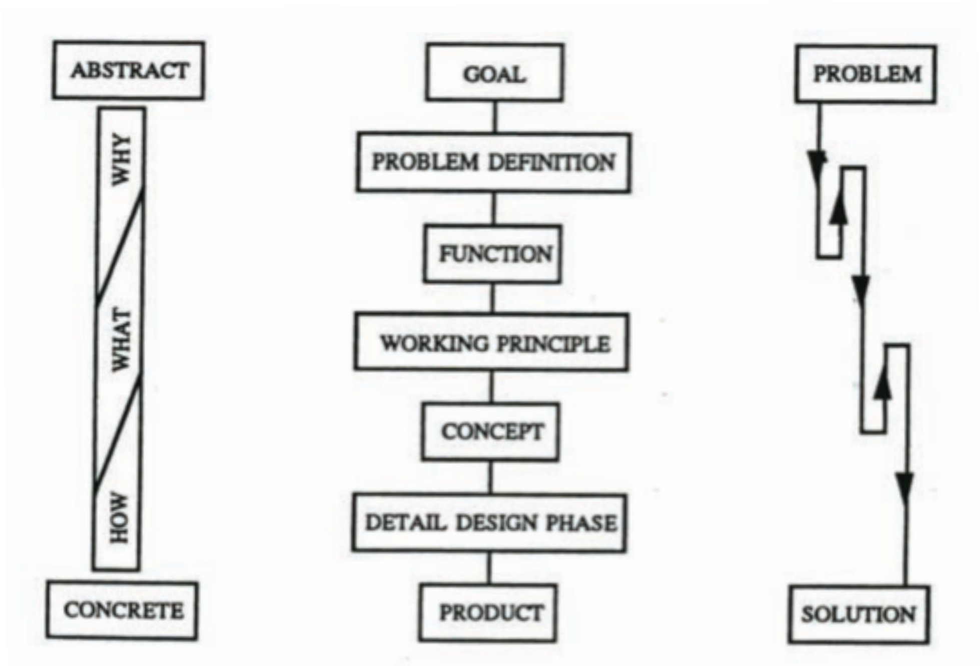


Figure 51 Design process model Kroonenberg and Siers
Source: Blessing (1994)

Design education at the faculty of Mechanical Engineering shifted its focus over the last years from the design process model of Kroonenberg and Siers (1992) to the design process model of Pahl and Beitz (1984). The scheme of the design process as proposed by Pahl and Beitz (1984) was already presented in Figure 37. Although the models of Pahl and Beitz (1984) and Kroonenberg and Siers (1992) differ the amount of explicit design phases, the characteristics of the sequential structuring of the design process are comparable, as well as the short cyclic iterative feedback loops.

Additionally to the dominant design process models of Pahl and Beitz (1984) and Kroonenberg and Siers (1992), the faculty of Mechanical Engineering at Delft University of Technology also incorporated the CE-mark as a guiding principle of minimal requirements for the design. The CE-mark is related to safety and ergonomics and is based on the following European standards:

- NEN-EN-ISO 12100-1&2 (safety of machinery, general principles for design)
- NEN-EN 1050 (safety of machinery, principles for risk assessment)

The CE-mark and related norms are not a method in itself, but part of an extended 'Construction Dossier', which systemizes the design process. The application of the 'Construction Dossier' as an explicit systemization of the design process can be marked as a methodological structure that frames the definition of the problem or opportunity space. The interpretation of the design process model at the faculty of Mechanical Engineering in or over several phases and corresponding design methods shows a systemization of design and relation with 'defined abduction'.

Other design methods at Mechanical Engineering, such as 'Brainstorming', 'Synectics' and 'Analogies Method', are more related to 'frame abduction'. However, although 'frame abduction' reasoning can be applied in some methods for framing the solution space, 'defined abduction' is the predominantly applied mode of reasoning. This is reflected in methods for the definition of functions and processes in respectively the 'Function Analysis' and the 'Process Analysis' in which functions and processes are evaluated and defined in relation to the 'Morphological Systematics Chart', as defined by Asimov (1962). The combined solutions as found by the 'Morphological Systematics Chart' can finally be compared with the 'Kesselring Method', whereby different alternatives can be compared on the trade-off between requirements for use and requirements for fabrication. Both, the 'Morphological Systematics Chart' and the 'Kesselring Method' are methods that are related to 'defined abduction'. These methods partly define the solution space. The methodological structures for design at the faculty of Mechanical Engineering have a focus on reducing the problem, opportunity, and solution space to reduce uncertainty. Therewith, the applied process models and methods focus on reducing the design space to structure the design process. The design reasoning at the faculty of Mechanical Engineering is therefore strongly related to the reasoning behind 'Systems Engineering'.

The reflection of design methods for framing the problem or opportunity space on the spectrum of abduction is given in Figure 52. In addition, the reflection of design methods for framing the solution space, presented on the spectrum of abduction, is given in Figure 53. An overview of the design methods that are commonly used at the faculty of Mechanical Engineering in relation to different design process phases is presented in Appendix A.5.

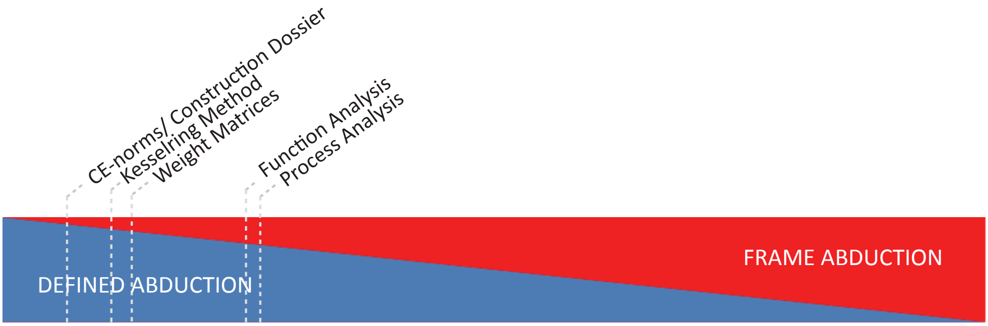


Figure 52 Modes of reasoning in design methods for framing the problem or opportunity space at faculty of Mechanical Engineering

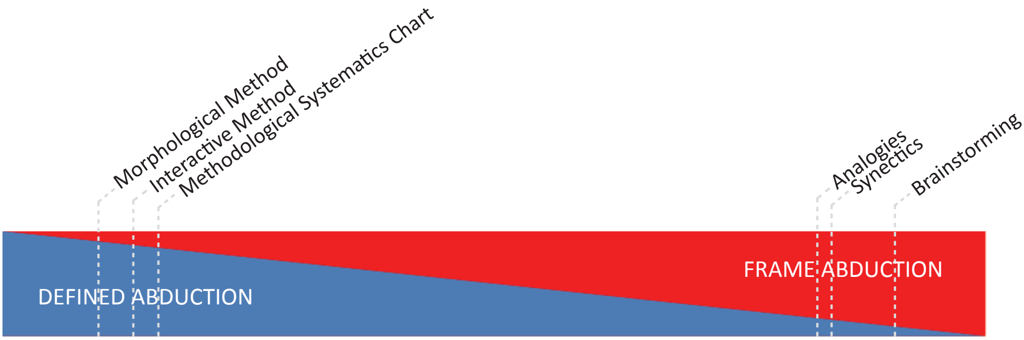


Figure 53 Modes of reasoning in design methods for framing the solution space at faculty of Mechanical Engineering

4.3.6 Methodological Spectrum and Characteristics

The research into design at different faculties of Delft University of Technology resulted in a spectrum of design methodologies and methods per faculty. A short overview of the dominant design process models for every investigated faculty is given below:

• Aerospace Engineering	Pahl and Beitz (1984)
• Architecture and the Built Environment	Schön (1983)
• Civil Engineering and Geosciences	Roozenburg and Eekels (1995)
• Industrial Design	Roozenburg and Eekels (1995) Buijs (2003) Hekkert and Van Dijk (2011)
• Mechanical Engineering	Pahl and Beitz (1984) Kroonenberg and Siers (1992)

The design process models of Pahl and Beitz (1984), Roozenburg and Eekels (1995), and Kroonenberg and Siers (1992) can be typed as engineering design process models, incorporating defined sequentially structured design stages. The design process models of Buijs (2003) and Hekkert and Van Dijk (2011) are also sequentially structured, but connect different product life-cycles in relation to the development of its use.

Although the model of Schön (1983) also incorporates a sequential structure, the translation between design phases is more related to the introspective domain with a more open definition and interpretation of the design phases. This distinguishes design at the faculty of Architecture and the Built Environment from the other investigated faculties. The more elaborate focus on the interpretation of the different phases in the design process through design methods shows also a more specific differentiation in design between the different investigated faculties.

The combined perspectives of the reflection of design methods on the spectrum of abduction gives a qualitative indication for the dominant mode of reasoning regarding design at a given faculty. The interrelated position of designing at the investigated faculties, according to the research into design methods, is schematized in Figure 54. Again, the distances on the spectrum are meant position-wise, not scale-wise. In addition can be said that the position on the spectrum of abduction shows an indication of the mix between 'defined abduction' and 'frame abduction' for the different investigated faculties, and in relation to each other. It is not meant to define a position on the spectrum in absolute terms, but as a matter of characterizing reasoning in design for different fields of design.

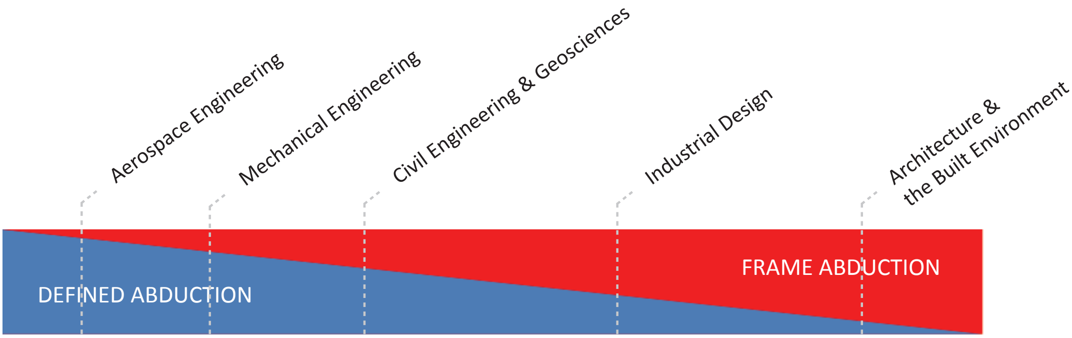


Figure 54 Spectrum of dominant modes of reasoning in methodological structures at different faculties of Delft University of Technology

The spectrum also illustrates that the faculties with 'engineering' in their name use many design methods in their general design process that are related to 'defined abduction'. The design reasoning at these faculties is strongly related to the reasoning behind 'Systems Engineering'. However, the application of decomposition and integration in 'Systems Engineering' differs per faculty in relation to the aspired artifact design. The specific design methods per faculty structure the aspired decomposition and integration.

Looking at the structuring of the design process, especially design at Aerospace Engineering and Mechanical Engineering is systematically structured through design process models, and the interpretation of design in the different design phases. These faculties focus on a defined problem or opportunity space and standardization of options for the solution space. Although the design process can incorporate standardization, not every design aspect will be well-defined in practice. There will remain a certain design space, even when this design space is bounded to a defined frame. Nevertheless, the dominant mode of reasoning in design at these faculties can be characterized by 'defined abduction'.

In contrast, the faculty of Architecture and the Built Environment uses design elements that can be characterized by 'frame abduction' or a mix between 'defined abduction' and 'frame abduction'. This is mainly because the methodological elements for design at the faculty of Architecture and the Built Environment leave more room for introspective reasoning, and therewith the definition of the artifact frame becomes subordinate to design itself.

At the faculty of Industrial Design, design education counts many methods for the interpretation of design in line with the design process model of Roozenburg and Eekels (1995), and increasingly influenced by the models of Buijs (2003), and Hekkert and Van Dijk (2011). At the faculty of Civil Engineering and Geosciences, design methods are used in relation to the design of the artifact itself, but also design methods that support the design and discussion of defining constraints for design. Therefore, design at the faculties of Civil Engineering & Geosciences and Industrial Design is positioned closer to the mid section of the spectrum. The dominant design process models at these faculties are sequentially structured in a defined order, but the interpretation of design for the different design phases is subordinate to the applied design methods. At Industrial Design also multiple influential design process models are available as options for application, which increases the possibilities for framing the design space. Industrial Design incorporates in this context more possibilities for framing of the constraints for design than Civil Engineering and Geosciences.

In addition to an investigation of the dominant modes of reasoning in design methods per faculty, design can also be described along methodological characteristics. These methodological characteristics give a more specified understanding of what 'defined abduction' and 'frame abduction' implies for design at the different faculties. Terms and descriptions that express the methodological characteristics for design at the investigated faculties are presented in Table 7.

Table 7 Methodological characteristics for design at Delft University of Technology

Faculty Delft University of Technology	Methodological characteristics
Aerospace Engineering	– Problem space and solution space are bounded to a defined frame – Reductionist approach in design methods – Parametrical orientation of design – Focus on integration as trade-off in functionality and system integrity – Feedback loops iteratively within and between sub-phases – Funnel design, frozen configurations in sequential design process phases
Architecture & the Built Environment	– Definition of design space subordinate to design – Intertwined design elements without hierarchy or sequential order – Design is mainly an introspective process with visual expressions like drawings and scale models that are part of the research by design – Design is in addition to problem-solving also discovery-driven and creation-driven – Less explicit design methodology than other design methodologies at investigated faculties at Delft University of Technology
Civil Engineering & Geosciences	– Problem space is derived from the context and bounded to a defined frame, solution space partly subordinate to a defined frame – Emphasize on location specific analyses – Functions and processes defined in relation to the artifact with focus on system integrity – Combination of conceptual design with well-known set of solutions, which have to deal with aspects with a certain probability, as stakeholders and environmental conditions – Long design process feedback loops after evaluation phase
Industrial Design	– Problem space, opportunity space, and solution space are subordinate to design in the choice of methodological structure, but explicitly defined when methodological structures are applied – The main phases are rationally ordered, but the available methods which can be used in these phases are a mix of design methods for ordering or to stimulate creativity, with incorporation of many different (small scale) design aspects – Design methods are predominantly related to user centered product design – There are also methods which can be applied in all phases, as structures for design and strategy – The feedback loops of the dominant design process model are long design process iterative after the evaluation phase, but depending on the used methods, short design process feedback loops can be incorporated – Benchmarking is an important aspect of designing
Mechanical Engineering	– Problem space and solution space are bounded to a defined frame – Focus on functionality and system integrity – Fabrication and design intertwined (therefore also 3 design phases instead of 4 in Kroonenberg and Siers (1992)) – Modular structures with integration focus on the coupling of framed sub-solutions (Morphological Chart) – Trade-norms (CE-norms) leading for design, which are intertwined with design process model – Short design process iterative loops per sub-system. Every sub-system is a smaller scale system, which is confronted with the same process steps, in line with the decomposition and reductionist approach

The methodological characteristics in Table 7 give in combination with the spectrum for abduction an indication of the characteristics of 'defined abduction' and 'frame abduction' in design, which is illustrated in Figure 55.

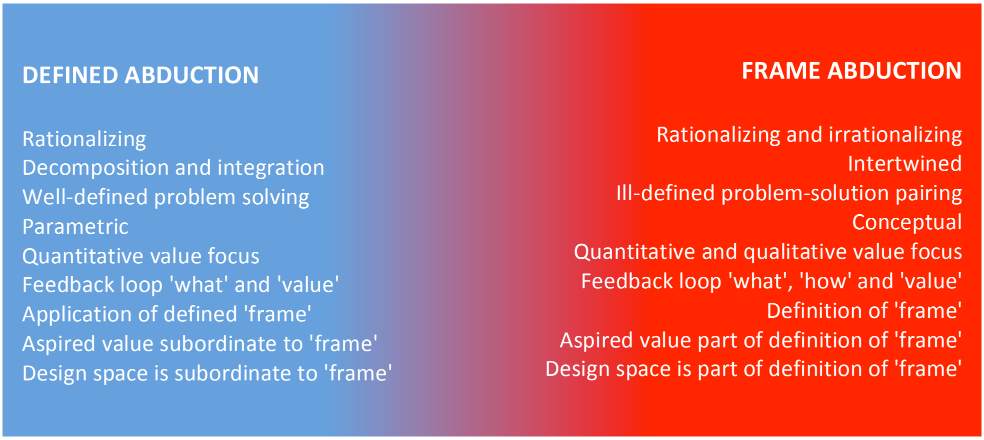


Figure 55 Characteristics regarding designing for 'defined abduction' and 'frame abduction'

4.4 Conclusions

The first part of the methodological framework for integrated design is at stake in chapter 4 of this dissertation. In chapter 4, research question 3 and sub-questions 3.1 and 3.2 are defined to research the relation between the methodological structure and the definition of the design space for integrated design. The definition of this relation aims understanding the influence of the framing of the methodological structure on the compatibility of multiple artifact frames. Research question 3 and sub-questions 3.1 and 3.2 are formulated as:

Research question 3:	What is the relation between the methodological structure and the definition of the design space for integrated design?
Sub-question 3.1:	How did methodological structures for design develop over time?
Sub-question 3.2:	How do currently used methodological structures frame design in different fields of design?

To formulate a conclusion with respect to research question 3, first of all, sub-question 3.1 and 3.2 are discussed. After sub-questions 3.1 and 3.2, research question 3 will be at stake.

Sub-question 3.1: How did methodological structures for design develop over time?

Design methodology with respect to methodological structures for design developed in design sciences from the sixties of the twentieth century. The first design methods were 'Positivist' inspired and striving for a systemization of design. A sequentially structured design process with an explicitly defined order of design phases characterizes this so-called ‘engineering design’.

After a period of development of methodological structures in relation to 'engineering design', the corresponding mode of reasoning in design was perceived as limiting in certain cases. Therefore, in addition to 'engineering design', a more 'Constructionist' and introspective oriented type of design, with less explicit methodological structures, started developing in design sciences. This less systemized structure of design gave also room for defining the artifact frame as part of the design itself. From the sixties of the twentieth century, methodological structures for design generally developed in two main modes of reasoning, which are described by Dorst (2011) as two types of abduction with respect to design. Dorst (2011) distinguishes 'abduction 1' and 'abduction 2' in this context. 'Abduction 1' is referring to the design of the 'what' or a 'thing', the actual artifact, while 'abduction 2' design refers to the 'what' or 'thing' and the 'working principle'.

In this dissertation, the two modes of reasoning that developed over time are formulated as 'defined abduction', referring to design within a defined artifact frame, and 'frame abduction', referring to design in which the definition of the artifact frame is part of the design itself. The different modes of reasoning represent a spectrum with respect to different interpretations of design and the definition of the design space with corresponding methodological structures.

Sub-question 3.2: How do currently used methodological structures frame design in different fields of design?

Methodological structures for design were investigated for different fields of design that refer to the design of an artifact. In this context, methodological structures at different faculties at Delft University of Technology that are related to the design of an artifact were investigated. The investigated faculties are:

- Aerospace Engineering
- Architecture
- Civil Engineering and Geosciences
- Industrial Design
- Mechanical Engineering

All investigated faculties refer to the design of an artifact, but show different interpretations of design through their methodological structures. The explicit methodological structures that were investigated are the 'design process model' and the 'design methods'.

With respect to the design process model, design at the faculties of Aerospace Engineering, Civil Engineering and Geosciences, Industrial Design, and Mechanical Engineering, all incorporate sequentially structured design process models with explicit defined design phases in a defined order. Although design at the faculty of Architecture and the Built Environment is structured through design elements as well, the order of sequence of the design elements is dependent on the design objective, as constructed by different defined futures. There is a predominant sequence of the design elements that is applied in many cases, which is comparable with the phasing of the design process at the Engineering faculties, but it is not always defined on beforehand. This also holds for design at the faculty of Industrial Design, where new influential design process models increasingly incorporate linking life cycles and start with an evaluation or reflection phase. The choice in design process models at the faculty of Industrial Design broadens the possibilities for framing the design space.

More differentiation between the faculties is found with respect to the design methods at the different faculties. The design methods structure design within different defined design phases and were reflected on a spectrum of abduction, ranging from 'defined abduction' to 'frame abduction'. For the faculties of Aerospace Engineering and Mechanical Engineering, 'defined abduction' is marked as the dominant mode of reasoning in design methods. The faculties of Civil Engineering and Geosciences and Industrial Design show a mix between design methods that refer to 'defined abduction' and 'frame abduction', in which design at Civil Engineering and Geosciences is overall more related to 'defined abduction' than Industrial Design. For design at the faculty of Architecture and the Built Environment, design methods are less explicitly defined than for the other investigated faculties.

The research into the design process models and design methods at different faculties at Delft University of Technology shows a spectrum of interpretations and applications of design. For methodological structures in which 'defined abduction' is the predominant mode of reasoning, design is mainly done within the defined space for design. For methodological structures in which 'frame abduction' is the predominant mode of reasoning, the definition of the space for design is also part of the design. 'Defined abduction' implies that design is methodologically structured by a defined artifact frame, while 'frame abduction' implies that design is methodologically structured in a way that the definition of the artifact frame is part of the design itself.

While design at different faculties all incorporate both 'defined abduction' and 'frame abduction', design at the faculty of Aerospace Engineering is predominantly structured in relation to a defined artifact frame. The design space is in that situation bounded. In contrast, design at the faculty of Architecture and the Built Environment is predominantly structured in a way that the definition of the artifact frame is part of the design itself. The design space is ill-defined in order to possibly incorporate opportunities, (re)frame the problem space, or develop new conceptual solutions.

The difference in design between Aerospace Engineering and Architecture and the Built Environment can be explained by the fact that the engineering disciplines use methodological structures with more institutionalized systemization, based on for example standards and norms, for aspects such as safety or ergonomics. These standards and norms are imposed from external institutions and frame in this sense the solution space. Although in the architecture practice, standards and norms are also part of reality, general design education at the faculty of Architecture and the Built Environment emphasizes the development of design skills, in which the definition of the artifact frame is part of the design itself. Introspective reasoning and reflection in short cyclic iterations are at the core of the design process as educated at the faculty of Architecture and the Built Environment.

The research into methodological structures for design at different faculties of Delft University of Technology shows that the educational direction of design courses and the development of methodological structures are based on interpretations of design. However, the research also implies that the methodological structures on their turn frame the interpretations of design.

Research question 3: What is the relation between the methodological structure and the definition of the design space for integrated design?

The conclusions for sub-questions 3.1 and 3.2 show a spectrum of abduction with respect to different modes of reasoning in design. Different fields of design are predominantly related to 'defined abduction' or 'frame abduction', which differentiates design in design with a defined artifact frame, and design in which the definition of the artifact frame is part of the design itself. The methodological structure frames reasoning in the design process along the spectrum of 'defined abduction' to 'frame abduction'.

With integrated design defined as the 'framing of the compatibility of multiple artifact frames', 'defined abduction' implies integrated design as the 'framing of the compatibility of multiple defined artifact frames'. This means that the level of compatibility between multiple artifact frames is also already defined for 'defined abduction'. The definition of the design space for integrated design is framed by the definition of the compatibility between multiple artifact frames and is therewith defined as well. Methodological structures that are predominantly related to 'defined abduction' are therefore related to the definition of the design space for integrated design in a context of a defined compatibility of multiple artifact frames.

For 'frame abduction', the definition of the artifact frame is part of the design itself. This means that the 'framing of the compatibility of multiple artifact frames' is subordinate to design for 'frame abduction'. Methodological structures that are predominantly related to 'frame abduction' are therefore related to the definition of the design space for integrated design in a context of a compatibility of multiple artifact frames that is part of the design itself.

The different relations between the methodological structures and the definition of the design space for integrated design will also result in different perspectives on integrated design. When artifact frames are predefined, integrated design will focus on the integration of the actual artifacts, which can be marked as a more technical interpretation of integrated design. When the definition of the artifact frames is part of the design itself, integrated artifact frames can lead to new typologies of artifacts, which can be marked as a more conceptual interpretation of integrated design. To what extent the artifact frames are predefined or part of the design itself, frames the definition of the design space for integrated design, and therewith also the interpretation of integrated design.

5 A Meta-Method for Solving Issues of Integration Through Integrated Design

5.1 Introduction

As part of the methodological framework for integrated design, chapter 4 defined the relation between the methodological structure and the definition of the design space for integrated design. Chapter 5 is about the development of a meta-method for solving issues of integration through integrated design. The meta-method refers to the conceptual approach that was developed in chapter 3 on how integrated design can lead to a state of abundance for the relation between different forms of aspired value. It is called a 'meta'-method because it can form a basis for the development of methods for integrated design for different applications. The meta-method for integrated design will be developed through an inductive approach of researching the methodological structure of different integrated design approaches in particular fields of application.

Chapter 5 is related to research question 4 and corresponding sub-questions 4.1 and 4.2. Research question 4 and sub-questions 4.1 and 4.2 are formulated as:

Research question 4:	How can a meta-method for integrated design support solving issues of integration?
Sub-question 4.1:	What are the key elements of the common ground in methodological structures of integrated design approaches?
Sub-question 4.2:	How can the key elements be translated into a meta-method for integrated design?

The aim of this chapter 5 is to describe a meta-method for integrated design that supports designers solving issues of integration in different fields of application. The meta-method will be described in the terminology of chapter 2. A conceptual approach on how integrated design can support solving issues of integration was already described in chapter 3. In chapter 5, the conceptual approach of chapter 3 is supported with a methodological structure for integrated design.

Section 5.2 starts, in relation to sub-question 4.1, with the description of the key elements of the common ground in methodological structures of integrated design approaches. Comparing different specific integrated design approaches and searching for common ground in their methodological structures will be of central attention in section 5.2. Thereafter, section 5.3 describes the translation of the defined key elements into a meta-method for integrated design, which is related to sub-question 4.2. Finally, section 5.4 contains the conclusions with respect to research question 4 and sub-questions 4.1 and 4.2.

5.2 Methodological Common Ground in Integrated Design Approaches

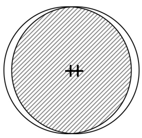
Section 5.2 will go into sub-question 4.1: 'what are the key elements of the common ground in methodological structures of integrated design approaches?'.

5.2.1 Methodological Structures of Integrated Design Approaches

As already mentioned in section 5.1, the meta-method for integrated design will be developed in this Chapter 5. This will be done through an inductive approach of researching the methodological structure of different integrated design approaches. These integrated design approaches are related to particular fields of application, but possibly contain a common ground that can be described through a meta-method.

An investigation of scientific literature resulted in a selection of integrated design approaches that are seemingly related to integration in accordance with compatibility level 5. Compatibility level 5 refers to an overall artifact frame in which the optimum aspired value for different artifact frames can be obtained. Integration in accordance with compatibility level 5 implies dissolution of issues of integration. It refers to a state of abundance with respect to the relation between different forms of aspired value. Integration in accordance with compatibility level 5 was already presented and described in Table 5 and Table 6, in respectively section 2.3.2 and section 3.3.1. The specific row that describes integrated design in accordance with compatibility level 5 in Table 6 in section 3.3.1 is presented separately in Table 8.

Table 8 Scheme of integrated design in accordance with compatibility level 5

 A B Level 5	Mutually compatible artifact frame A and artifact frame B. There is an overall artifact frame, which incorporates both optimum aspired value A and optimum aspired value B simultaneously	The optimum aspired value for both artifact frame A and artifact frame B can be obtained simultaneously when integrated

The integrated design approaches that were found in literature and 'seemingly related' to compatibility level 5, and will be researched on their methodological structure in this chapter 5 are:

a) Building with Nature (BwN)
b) Cradle to Cradle/ Design for Disassembly (C2C/ DfD)
c) Landscape Urbanism (LU)
d) Transdisciplinary Design (TD)
e) Value-Sensitive Design (VSD)

f) Universal Design (UD)
g) Inclusive Design (ID)
h) TRIZ
i) Framing (F)

The research into the integrated design approaches is exploratory of character and therefore 'seemingly related' is emphasized in this context. The selected and investigated integrated design approaches do not explicitly contain terms such as 'compatibility level 5', 'dissolution', or 'abundance' in their methodological description, but seem implicitly refer to these terms in their methodological structure.

In addition has to be said that although chapter 2 already illustrated that terms such as 'inclusive' and 'universal' are not suitable as interchangeable terms for 'integrated', the description of their methodological structure can possibly add to the development of a meta-method for integrated design. Therefore, approaches such as Universal Design and Inclusive Design are also investigated on their methodological structure, which means that the structure of the design process and the applied design methods are investigated. A scheme of the inductive approach for the research into the methodological common ground of different integrated design approaches is given in Figure 56.

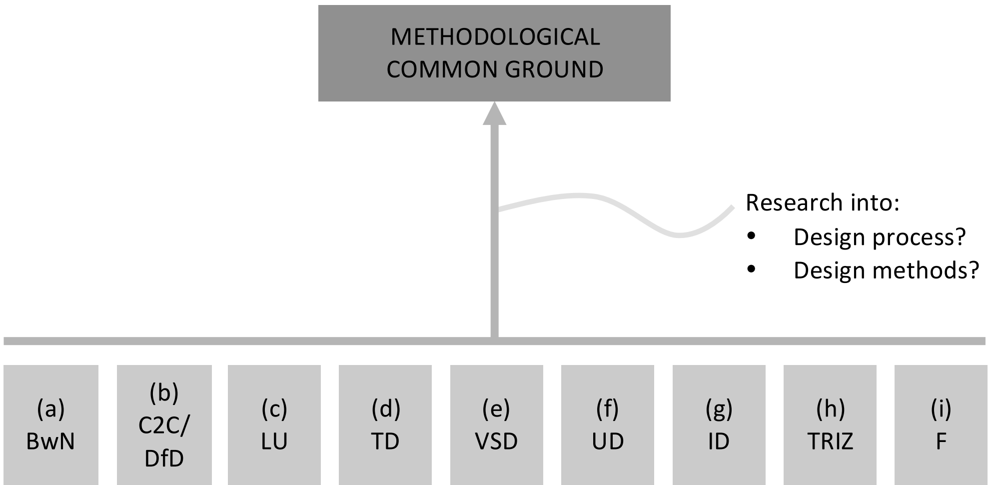


Figure 56 Inductive approach for research into the methodological common ground of different integrated design approaches

The different integrated design methods (a) till (i) will be described briefly from this point, starting with Building with Nature. Thereafter, a description of differences and commonalities in these integrated design approaches will be given before formulating a methodological common ground that forms the basis for developing a meta-method for integrated design.

a) *Building with Nature*

Building with Nature is an approach for which building processes and natural processes are aligned in such a way that these different processes do not conflict with each other. An example of Building with Nature was given with the case of the Sand Motor in section 3.3.2. The aspired value 'flood risk reduction' was in the example of the Sand Motor aligned with the aspired value of 'ecosystem quality'. The working principle of the Sand Motor facilitates both forms of aspired value.

From a methodological point of view, De Vriend and Van Koningsveld (2012) define five design steps to obtain alignment in the Building with Nature approach:

1) Understand the system (including ecosystem services, values and interests)
2) Identify realistic alternatives that use and/or provide ecosystem services
3) Evaluate the qualities of each and preselect an integral solution
4) Fine-tune the selected solution (practical restrictions and the governance context)
5) Prepare the solution for implementation in the next project phase

The sequence of the five design steps also represents a design process for the Building with Nature approach.

Understanding the system, as part of design step 1 in Building with Nature, can be interpreted as an identification of the system constraints. In design step 2, the focus is already on the identification of alternatives. This can be related to synthesizing. Design step 2 is divergent of character, where after design step 3 to design step 5 are convergent of character.

Design step 3 is related to an 'integral solution'. The term 'integral' is not explicitly defined in the Building with Nature approach, but implicitly used in reference to a 'whole', as described in chapter 2.

b) *Cradle to Cradle/ Design for Disassembly*

Cradle to Cradle is the approach that was brought under great attention by architect William McDonough and chemist Michael Braungart (McDonough & Braungart, 2002). Their approach tried to bring a transformation from Cradle to Grave to Cradle to Cradle. Therewith, they proposed a circular flow of material, in which waste is defined as food for a new process. However, while their book incorporates aspects to pay attention to in the transformation to a Cradle to Cradle process, the book is still descriptive of character.

Comparable to publications on the closely related Cradle to Cradle approach, publications on Design for Disassembly are also descriptive instead specific in terms of methodological structure. In publications on Design for Disassembly, key principles or design rules are given, but the methodological implications for how to built up a design process in a certain context towards a defined objective are less explicit (Bogue, 2007; Rios et al., 2015).

c) *Landscape Urbanism*

Landscape Urbanism was described by Elizabeth Mossop (2006), as bringing together a number of different landscape-generated ideas in the exploration of contemporary urbanism. Landscape Urbanism as a term was born in North America, but comparable terms as 'critical regionalism' by Alexander Tzonis and Liane Lefaivre can be seen as the European counterparts in the development of Landscape Urbanism.

Pollak (2006) describes 'constructed ground' as the main representation of a hybrid framework that crosses between architecture, landscape architecture, and urban design. This framework can support using the landscape as both a structuring element and a medium for rethinking urban conditions, to produce everyday urban spaces that do not exclude nature. Its goal is to address simultaneously the concerns of architecture, landscape, and city.

Other efforts were made in the description of the relation between infrastructure and its landscape by Nijhuis and Jauslin (2015), and Shannon and Smets (2010). However, these publications were descriptive of character with a focus on the elements of design or best practices. In a broader scientific context, these publications do not give sufficient insight in an explicit methodological description and explanation of the design process.

All three applications, Building with Nature, Cradle to Cradle/ Design for Disassembly, and Landscape Urbanism, show transdisciplinary approaches of design. However, they all focus on a certain field and do not automatically cover a broader application for integrated design.

d) *Transdisciplinary Design*

The transdisciplinary practice differs from multi-, and interdisciplinary by the development of a new common mode of reasoning C, as defined in this scheme by mode of reasoning A and mode of reasoning B, represented by for example respectively stakeholder A and stakeholder B. The difference between multi-, inter-, and transdisciplinary is schematized in Figure 57. Transdisciplinary design tries to overcome, what McGregor (2015) describes as, 'the exclusive logic that assumes that ideas that are antagonistic cannot be connected' (p. 17). To support transdisciplinary practice with a methodological structure, Kahn and Prager (1994) propose in the context of higher education and professional training five 'milestones' for successful transdisciplinary practice, namely:

1) Listening across disciplinary gulfs
2) Learning the language and ideas of other disciplines
3) Developing a common language for new conceptual development
4) Jointly developing new methods and measures
5) Conducting research that reflects disciplinary integration

The sequence of the five 'milestones' also represents a design process for transdisciplinary design.

The first 'milestone' refers to the identification of constraints and frames for different disciplines. The second 'milestone' builds on this first 'milestone' by reflecting on other disciplines. In that context, constraints and frames for different disciplines is reflected on each other. The third 'milestone' is divergent of character, in the search for a common language for new conceptual development. The fourth and the fifth 'milestone' are convergent of character, when the common language for new conceptual development is added with the development of methods and measures for application, and the reflecting research with respect to integration.

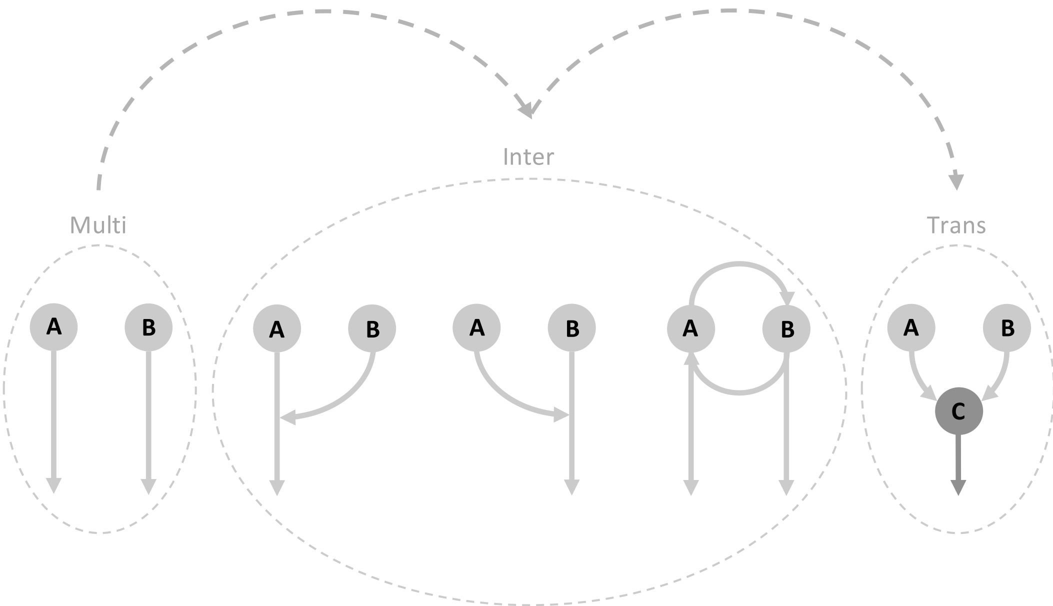


Figure 57 Scheme of multi-, inter-, and transdisciplinary

e) Value-Sensitive Design

As described by Friedman et al. (2006), Value-Sensitive Design incorporates a tripartite methodology, consisting of 'conceptual', 'empirical', and 'technical' investigations. In the conceptual investigation, questions such as 'what are the direct and indirect stakeholders?', 'how are the stakeholders affected?', and 'what values are implicated?' are for example at stake (Friedman et al., 2006). These questions illustrate that the conceptual investigation is about the identification of constraints in Value-Sensitive Design.

The empirical investigation focuses on the results of the conceptual investigation in its particular context. Questions that are related to the empirical investigation are for example 'how do stakeholders prioritize values in design trade-offs?', and 'is there a difference between what stakeholders theoretically prioritize in comparison to what they prioritize in actual practice?'. To obtain answers on these questions, quantitative and qualitative methods can be used for the empirical investigation, such as observations, interviews, and relevant documents (Friedman et al., 2006).

As a third part of the tripartite methodology of Value-Sensitive Design, the technical investigation focuses on the application of Value-Sensitive Design through technology itself (Friedman et al., 2006). The conceptual, empirical, and technical investigation are interrelated, and the design process is iterative (Manders-Huits, 2011; Winkler & Spiekermann, 2018).

Although, the conceptual, empirical, and technical investigation give direction for investigation, the different investigations are not elaborated explicitly in a design method with design steps and a design process model (Manders-Huits, 2011; Winkler & Spiekermann, 2018). Manders-Huits (2011) states that one of the aspects that is lacking in the methodology of Value-Sensitive Design is an explicit ethical theory for dealing with value trade-offs.

f) Universal Design

A design approach that was also already investigated on its terminology in chapter 2 is Universal Design. 'Universal' as a term was in chapter 2 considered as not suitable as an interchangeable term for 'integrated'. However, the methodological structure can possibly add to the development of a meta-method for integrated design. Therefore, Universal Design is also investigated on its methodological structure. As an explicit representation of Universal Design, the architect and designer Ron Mace, defined seven principles for Universal Design, which are formulated in Null (2014) as:

1) Equitable use
   The design does not disadvantage or stigmatize any group of users
2) Flexibility in use
   The design accommodates a wide range of individual preferences and abilities
3) Simple, intuitive use
   Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level
4) Perceptible information
   The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities
5) Tolerance for error
   The design minimizes hazards and the adverse consequences of accidental or unintended action
6) Low physical effort
   The design can be used efficiently and comfortably, with a minimum of fatigue
7) Size and space for approach and use
   Appropriate size and space is provided for approach, reach, manipulation, and use, regardless of the user's body size, posture, or mobility

Looking at the seven principles of Universal Design, as defined by Ron Mace, has to be stated that these principles are descriptive and generic characteristics to take into account in the design process, but cannot be used as methodological structures for the design process itself.

g) Inclusive Design

As chapter 2 already showed, Inclusive Design and Universal Design differentiate with respect to trade-offs. Inclusive Design is related to 'reasonable accessibility', while Universal Design is related to 'comprehensive accessibility', regardless of age, ability, or status. However, the fields of application of both approaches are comparable, and accessibility in both approaches is related to human ability. However, this human ability can be diverse and refer to for example older users, disabled people, or people that do not have access to facilities due to their social status. In addition, some issues regarding accessibility are culturally dependent and are perceived differently by people in different cultures.

With respect to the methodological structure of Inclusive Design, Keates and Clarkson (2003) define a '7-level design approach', which are part of different design stages. The different levels and corresponding design stages are:

Stage 1: Problem Definition

1) User wants/ aspirations
   Identify the complete problem to be solved/ validate problem definition
2) User needs
   Specify the functionality to be provided/ verify function definition

Stage 2: System Definition

3) User perception
   Develop a minimal, but sufficient representation of the system status/ verify user perception
4) User cognition
   Structure the interaction to match the user's expectations/ verify user understanding
5) User motor function
   Develop quality of control and user input/ verify user comfort

Stage 3: System Validation

6) User practical acceptability
   Evaluate system functionality, usability, and accessibility/ validate practical acceptability
7) User social acceptability
   Evaluate social acceptability and match to user wants/ validate social acceptability

The different levels and corresponding design phases represent a methodological structure for Inclusive Design and show a sequential order of phases from a problem-solving perspective.

In stage 1, the identification of the user wants and user needs are at central attention. Stage 2 is a synthesizing stage, in which solutions for inclusion are developed. Stage 3 refers to validation of practical and social acceptability of the design for the user.

h) TRIZ

TRIZ (Russian: Teorya Resheniya Izobreatatelskikh Zadatch, translated: 'the theory of innovative problem-solving) was developed by Genrich Altshuller between 1940 and 1970 after selecting and studying 40.000 patents on their commonalities. Altshuller developed from this study into patents 40 Inventive Principles and 39 Engineering Parameters that are generic for many engineering design fields (Savransky, 2000). Examples of Engineering Parameters are 'weight of moving object', 'brightness', and 'adaptability'. These Engineering Parameters can also be translated as the technical characteristics of the engineering design. Examples of Inventive Principles are 'segmentation', 'universality', and 'feedback'. However, the Inventive Principles are more generic characteristics and not structured in an explicit design method or process model.

i) Framing

Framing, as a derived term from the description of Schön (1983) was further developed by Dorst (2011; 2015), who described framing as the 'act of proposing hypothetical patterns of relationships' (Dorst, 2015, p. 53). The frame creation process model as introduced by Dorst (2015) consists of nine sequentially structured phases, which are related to ten principles of frame creation. Dorst (2015) formulates these ten principles of frame creation as:

1) Attack the context
2) Suspend judgment
3) Embrace complexity
4) Zoom out, expand, and concentrate
5) Search for patterns
6) Deepen themes
7) Sharpen the frames
8) Be prepared
9) Create the moment
10) Follow through

The ten principles of frame creation show a sequential structure from 1 to 10 and therewith also describe the structure of a design process. Although the ten principles of frame creation are still abstract in description, these principles represent the implications of action for the sequentially structured phases.

The first four principles of framing, as described by Dorst (2015), are divergent of character. The focus is on the context and on zooming out from the original problem. Framing in the description of Dorst (2015) is focused on a broad scope in the first phases of the design process. From principle 5 and 6, the principles become convergent of character.

5.2.2 Differences and Commonalities in Integrated Design Approaches

Reflecting on the investigated integrated design approaches, these approaches show differences and commonalities. First of all, there is a difference in the explicitness of the methodological structure between different approaches for integrated design. The methodological structure of Building with Nature, Transdisciplinary Design, Inclusive Design, and Framing shows a more explicit differentiation in design steps. Cradle to Cradle, Design for Disassembly, Landscape Urbanism, Universal Design, Value-Sensitive Design, and TRIZ are less explicit methods in terms of methodological structure. For example, Universal Design and TRIZ contain principles for design, but do not refer to explicit design steps or design phases.

Besides the identification of differences in explicitness between different approaches for integrated design, there are also commonalities between the more explicit methodological structures of design approaches. In this context, the approaches Building with Nature, Transdisciplinary Design, and Framing, all show a general structure of a sequential order of divergence and convergence for both the definition of the problem or opportunity, and the solution space. For example, Framing starts directly with divergence with respect to the definition of the problem space in 'attack the context' in principle one. The methodological structure of divergence and convergence for the definition of the problem, opportunity, and solution space in these design approaches shows that the definition of the artifact frame is part of the design itself in these integrated design approaches. This corresponds to 'frame abduction'. However, to which extent, and in which way the definition of artifact frames is part of the design itself differs per design approach. For example, the specific focus of Building with Nature is on the integration of 'building' and 'nature'. For Transdisciplinary Design holds that the specific focus is on the integration of disciplines.

Looking at another integrated design approach, namely Inclusive Design, the methodological structure of Inclusive Design was translated into a '7-level design approach' by Keates and Clarkson (2003), which was described in (g) of section 5.2.1. The seven different levels also show a sequential order of design stages, differentiated in 'problem definition', 'system definition', and 'system validation' (Keates & Clarkson, 2003). These differentiated design stages in Inclusive Design also show a structure of divergence and convergence with respect to the definition of the problem space. However, the definition of the solution space focuses on the system definition from the beginning and the process in defining the solution space is more convergence of character. Therefore, the methodological structure of Inclusive Design is different of character than the methodological structure of Building with Nature, Transdisciplinary Design, and Framing.

The investigation of integrated design methods shows that Building with Nature, Transdisciplinary Design, and Framing contain the most explicit methodological structures. Although the different design steps and design phases have a different focus, the methodological structure shows common ground in the sequential order of divergence and convergence for both the definition of the problem, or opportunity space, and the definition of the solution space. In Table 9, the methodological structure of these three integrated design approaches are presented in relation to each other, and design steps are clustered on common ground.

Although the methodological structures of the different approaches show common ground, the specification and amount of design steps per cluster can differ, as can be observed in Table 9. In addition, the strict clustering and separation of design steps can be discussed. However, the clustering and definition of design steps and main design phases are meant to illustrate the methodological common ground in order to support the development of a meta-method for integrated design. Therefore, a strict clustering and separation of design steps, or differentiation in amount of design steps per cluster does not undermine the aim of this research.

The overview in Table 9 shows that Building with Nature and Transdisciplinary Design both contain a phase that is about the identification of the main system aspects, which can be specified in building systems, eco-systems, or disciplines, with respect to these integrated design approaches. Framing refers in this context directly to 'attack the context' and is therewith more divergent from the start. However, 'attack the context' is also described by Dorst (2015) from a problem-solving perspective, and is therefore also related to understanding of the design challenge in its context, before synthesizing. Building with Nature and Transdisciplinary Design also incorporate the investigation of the context, as part of the design process. Building with Nature incorporates the investigation of the context through describing the building system in relation to ecosystem services, values and interests. Transdisciplinary Design incorporates the investigation of the context through learning the language and ideas of other disciplines. In this way, Building with Nature, Transdisciplinary Design, and Framing are all about the understanding of the main system aspects in relation to the system scope and constraints.

With respect to the design scope, the specific design approaches in Table 9 describe a divergent and convergent phase to define the design challenge. From the definition of the design challenge, the design process also contains a divergent and convergent phase towards integration. With respect to the solution space, different alternatives are identified and developed, which comprehend a new conceptual model or pattern in the first place. Secondly, the different methodological structures show convergence when the design steps and phases contain actions of evaluation, and further development, deepening and sharping of methods, measures, and frames.

Table 9 Overview of common ground in methodological structures in relation to the main design phases and design steps of integrated design approaches

Common ground		↔	**Integrated design approaches**		
Main design phases	**Design steps**	↔	**Building with Nature**	**Trans-disciplinary Design**	**Framing**
Understanding the system in its context	**Identifying main system aspects**	↔	Understand the system (including ecosystem services, values and interests)	Listening across disciplinary gulfs	Attack the context
	Understanding main system aspects in relation to system scope and constraints			Learning the language and ideas of other disciplines	Suspend judgment
Synthesizing	**Searching for common ground as a fundament for integration**	↔	Identify realistic alternatives that use and/or provide ecosystem services	Developing a common language for new conceptual development	Embrace complexity Zoom out, expand, and concentrate Search for patterns
	Deepening and structuring of the fundament for integration			Jointly developing new methods and measures	Deepen themes
Translating design into implementation	**Reflecting on design**	↔	Evaluate the qualities of each and preselect an integral solution	Conducting research that reflects disciplinary integration	Sharpen the frames
			Fine-tune the selected solution (practical restrictions and the governance context)		
	Preparing for implementation	↔	Prepare the solution for implementation in the next project phase		Be prepared Create the moment Follow through

The structure of divergence and convergence to define the problem or opportunity, and solution space is part of the investigation of the design space for integrated design. This design space determines the level of compatibility and the perspective on integrated design, as concluded in chapter 4. Also a well-defined problem or opportunity can be incorporated through (re)framing the well-defined problem or opportunity. Figure 58 shows a scheme of the common ground in the design process of the integrated design approaches Building with Nature, Transdisciplinary Design, and Framing.

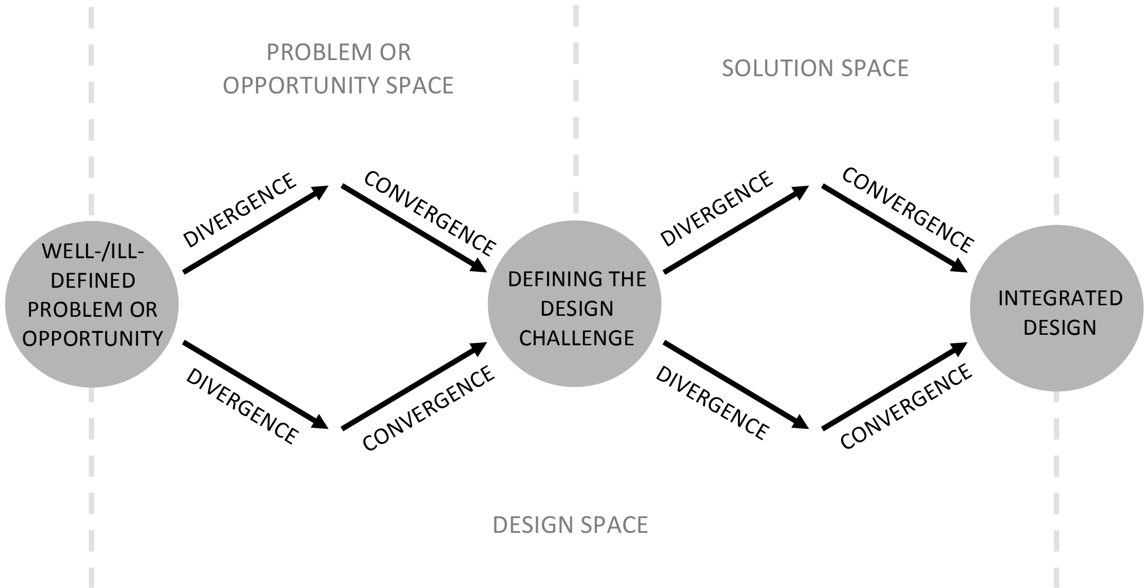


Figure 58 Scheme of the common ground in the design process of integrated design approaches

When the definitions of the problem, opportunity, and solution space are subordinate to design, the dominant mode of reasoning is referring to 'frame abduction'. The structure of divergence and convergence for the definition of the design challenge and the integrated design in Building with Nature, Transdisciplinary Design, and Framing shows that these integrated design approaches incorporate 'frame abduction'. Even more, to create and obtain integrated designs in accordance with compatibility level 5, 'frame abduction' seems to be an essential mode of reasoning in the design process.

However, the design steps of divergence and convergence for both defining the problem or opportunity space, and the solution space, are abstract in the context of the defined common ground. What these design steps imply in the context of the development of a meta-method for integrated design is part of research in section 5.3 of this dissertation.

5.3 A Meta-Method for Integrated Design

After defining the key elements of the common ground in methodological structures of integrated design approaches, section 5.3 is related to sub-question 4.2: 'how can the key elements be translated into a meta-method for integrated design?'.

A conceptual approach on how integrated design can lead to a state of abundance for the relation between different forms of aspired value was developed in section 3.3.3 of this dissertation. To support this conceptual approach by a methodological structure, the key elements of the common ground, as described in section 5.2, are in this section 5.3 be translated into a meta-method for integrated design. However, before introducing a meta-method for integrated design, the key elements of the common ground of a methodological structure for integrated design are translated into the terminology of chapter 2 in section 5.3.1.

5.3.1 Framing the Compatibility of Artifact Frames

In chapter 2, 'integrated design' was described as the 'framing of the compatibility of multiple artifact frames'. In addition, chapter 4 showed that for different faculties at Delft University of Technology interpretations of design and integration are a matter of framing. In the design courses at the different investigated faculties, students are therefore mainly educated in methodological structures that refer to different forms of framing, which determines the compatibility of different artifact frames.

The research into the design methodologies at different faculties of Delft University of Technology showed that the framing of design and integration can be defined along a spectrum from 'defined abduction' to 'frame abduction', respectively design within a defined artifact frame, and design in which the definition of the artifact frame is part of the design itself. Design in which the definition of the artifact frame is part of the design itself gives opportunities to (re)frame and obtain compatibility level 5. By obtaining compatibility level 5, also dissolution and a state of abundance for the relation between different forms of aspired value can be obtained. However, understanding how to frame the compatibility between different artifact frames also requires understanding how to frame the artifact frame itself.

In order to develop a meta-method for integrated design, the framing of the artifact frame will be researched on a more fundamental layer. First, the framing of the aspired value will be elaborated, where after framing of the working principles is at stake. At last, framing of the artifact frame will be discussed, as constructed from the framing of the aspired value and the framing of the working principles.

Framing Aspired Value

A general understanding of how people value can support the framing of the aspired value. In the context of the frame dependency of people's valuation, it was Markowitz (1952) who already wrote about people's valuation in terms of gains and losses, instead of absolute numbers. In later research, Ellsberg (1961) added the notion that people change their decision-making behavior when uncertainty has to be taken into account, which he translated in the Ellsberg Paradox. Ellsberg (1961) concluded that people are risk aversive in the case of higher uncertainty. Build on these earlier contributions, Kahneman and Tversky (1979) proposed in their so-called Prospect Theory that people's valuation is 'reference point dependent', which results in behavior of 'loss aversion' and situations of 'marginal utility'. These different studies in three different decades from the second half of the twentieth show that value and valuation are a matter of perception, which is an essential characteristic with respect to the framing of the aspired value. The perceived value is determined by the interplay of 'observation' and 'context'. An example of a context factor is the 'role' of a stakeholder. It is possible that from the perspective of a certain stakeholder role, people aspire a different value than their personal aspired value. For example, in the role of a project developer, a person can have an interest in the availability of a natural area for construction activities. However, it is possible that from a personal point of view this person is more a proponent of maintaining this natural area instead of using it for construction activities.

In addition, the perception of value can also change over time. The perception of the value of a house can grow or decline with the memories that are related to that house. Also, people are nowadays more aware of aspects such as sustainability and livability than a couple of decades ago. The perception of for example the livability of a street or sustainability of the products people evolves over time. These examples show that 'time' is also a context factor, and that the perception of value should therefore be distinguished from the absolute value.

To frame the aspired value, first of all the 'reference point' of the different stakeholders should be identified. Thereafter, the context factors in relation to this 'reference point' should be identified to construct a structure of constraints that frame the definition of the aspired value for different stakeholders. After the identification of the structure of constraints that frame the definition of the aspired value, the constraints can be investigated along the spectrum of constraints, respectively differentiated in 'intrinsic', 'imposed', and 'self-imposed' constraints, which was presented in section 3.2.2. The differentiation in constraints along this spectrum gives an overview of the constraints that can be (re)framed.

Section 3.2.3 of this dissertation already showed that constraints have a layered structure that appeal to the typology of constraints of 'intrinsic', imposed', and 'self-imposed'. Section 3.2.3 explained that conflicting forms of aspired value does not have to conflict on the level of values, that refer to the level of intrinsic constraints. Therefore, a designer can search for common values as a fundament for integration. The common values can be used for the development of working principles, where after the forms of aspired value can be (re)defined.

Framing Working Principles

The second component of the artifact frame, in addition to the aspired value, is the 'working principle'. A 'working principle' (how) is in the scheme of Dorst (2011) the connection between a 'thing' and the 'aspired value'. In other words, the 'how' of the 'thing', which should lead to the 'aspired value', is represented by the 'working principle'. The example of the Sand Motor in section 3.3.2 already showed that different working principles can lead to the aspired value, namely specific local reinforcement versus the gradual development through sand distribution along the coastline. The gradual development also gave opportunities for ecosystems to adapt and develop.

In addition to the Sand Motor, as an example of framing of working principles, an example case for the integration of wastewater treatment will be given to illustrate the framing of working principles and corresponding dissolution of issues of integration.

Example case: Organica Water Wastewater Treatment
Organica Water is a Hungarian company that was established in 1998. Although started as a traditional wastewater treatment company, it also investment in the development of sustainable wastewater treatment technologies and facilities. In 2007, they sold their traditional business and focused since then exclusively their developed Food Chain Reactor (FCR).

The FCR is a facility in which the treatment of wastewater is done through natural and artificial root structures. In this way the wastewater can be filtered without large concrete basins that take a lot of space and without hindering odors. The sequential process of filtration in the Organica Water facility is schematized in Figure 59.

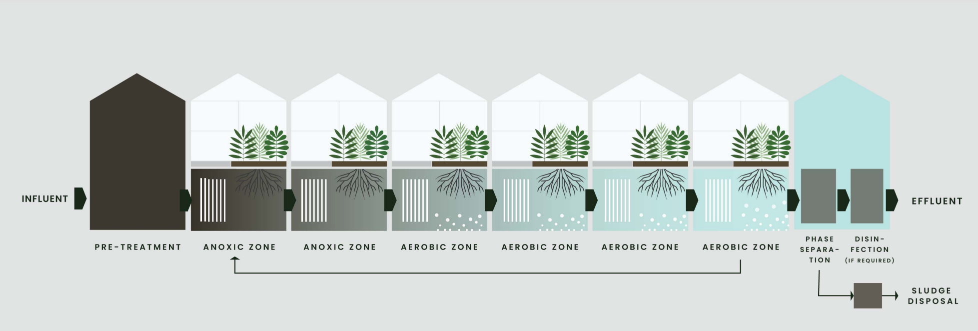


Figure 59 Sequential filtering process in an Organica Food Chain Reactor
Source: Organica Water (n.d.)

Organica Water showed over the years that the FCR represents a working principle of wastewater filtration that can be integrated in accordance with compatibility level 5 with other forms of aspired value. The aspired value of water filtration can through the FCR facility be integrated with the development of green public space in the form of for example a botanical garden. In addition, the absence of hindering odors gives opportunities to construct the wastewater treatment facility in dense urban areas.

Figure 60 shows a traditional wastewater treatment plant in comparison to the facility of Organica Water.

a) Traditional facility

b): Organica FCR facility

Figure 60 Traditional wastewater treatment facility vs. Organica FCR facility
Source: a) Arup (n.d.); b) Organica Water (n.d.)

Different artifact frames are compatible through the design of the working principle of the FCR, as is presented in comparison to a traditional solution in the schemes of Figure 61. The FCR design represents the intervention in order to dissolve the value conflict between the aspired value of water filtration or clean water, and the aspired value of spatial quality. It even shows opportunities for creating high quality public space through vegetation, while this same vegetation also has a major role in the filtration process.

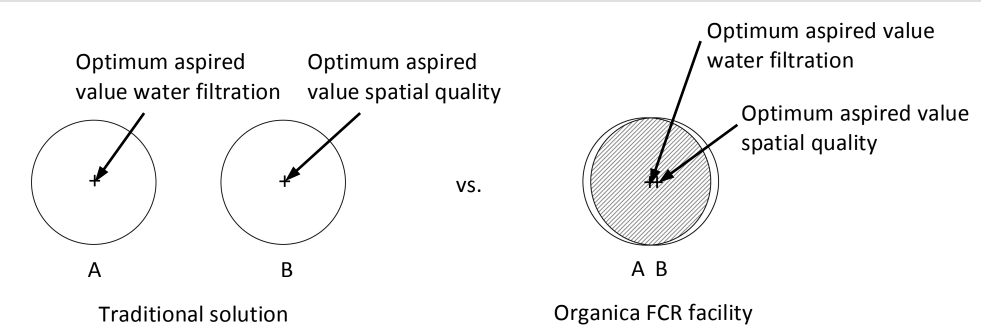


Figure 61 Schemes of the levels of compatibility of a traditional solution (compatibility level 1) versus Organica FCR facility (compatibility level 5)

In Jakarta, the wastewater treatment of Organica Water brought opportunities for integration in a specific case. The motivation for the need of a FCR is caused by a couple of factors. First of all, Jakarta's land costs are around 25.000 USD per square meter. In addition, this capital of Indonesia has to deal with land subsidence. Some parts of Jakarta are already 3 to 4 meter below sea level, and subsidence continues with the extraction of ground water (Organica Water, 2015a).

In this context, real estate developers have to come up with solutions in which wastewater treatment and real estate development go together. In such situations, conventional designs incorporate wastewater treatment normally in basement facilities. However, these facilities also come with hindering aspects such as 'offensive odors', 'poor esthetics', and 'decreased land value around wastewater facilities'.

To decrease ground water extraction, and therewith the speed of subsidence, and to meet water demands in Jakarta, city policies prescribed for example mandatory rainwater harvesting, mandatory green areas in every development, and a maximum amount of ground water extraction per building. In addition, a tariff on ground water extraction was introduced (Organica Water, 2015a).

The combination of all these factors led to the need for a new conceptual design for integration of different forms of aspired value. In this context, the wastewater treatment facility of Organica Water can be integrated in a dense urban area without the hindering aspects of traditional facilities and can lead to a state of abundance instead of a state of conflict for the relation between different forms of aspired value. The facility can function as a green space, which is open for the public in an urban center, while filtering wastewater in ecological sustainable ways. Figure 62 presents an artist impression of the design of the facility in Jakarta. ■

Figure 62 Artist impression wastewater treatment facility Jakarta
Source: Organica Water (2015b)

As mentioned in chapter 2, a 'thing' is not exclusively defined in relation to artificial spatial objects like bridges or buildings, but can also be related to artifacts like for example a business model (Brenner & Uebernickel, 2016). In that context, the change in business model of Rolls Royce aircraft engines is a famous example that shows the impact of the framing of working principles. Instead of designing a business model, which is mainly based on product quantity sales, Rolls-Royce transformed, for a large part of its aero-engine manufacturing, its business model towards service-based sales. The main drivers of the business model changed from quantity of sales towards quantity of hours of performance. The maintenance of their products was also incorporated in the service based business model and resulted in more reliable and longer performing products with better sales rates (Johnston, 2017). Another more elaborate example of business model innovation is given for the case of Take Back Chemicals. Take Back Chemicals refer to a similar business model innovation as mentioned for the Rolls-Royce case.

Example case: Take Back Chemicals

Take Back Chemicals is business model that aims to increase the effect of the chemicals used. A traditional business model is based on the idea of sales per quantity. However, Take Back Chemicals is based on the effect or performance of the chemical. The business model changes in that context from €/ton chemical supplied to €/ton treated product (Royal HaskoningDHV, 2017a). Take Back Chemicals changes in this way the incentive of the manufacturer from selling as much chemicals as possible towards delivering as much effect per chemical as possible. The interest of the user to obtain the best performance per unity of product is through Take Back Chemicals as a business model aligned with the interest of the manufacturer to have a profitable business, as graphically schematized in Figure 63.

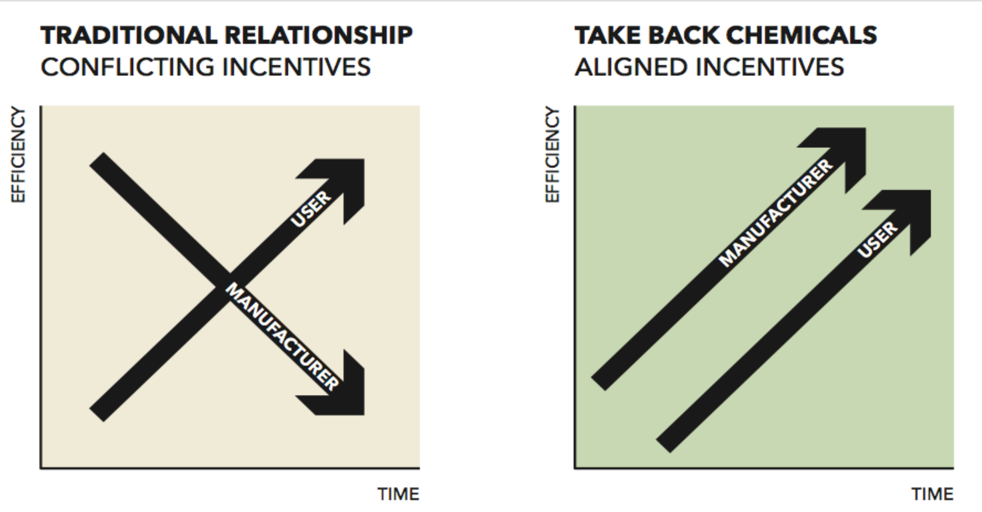


Figure 63 Relation between incentives of manufacturer and user for a traditional business model and Take Back Chemicals model
Source: Royal HaskoningDHV (2017b)

The aspired value of the manufacturer is related to the profitability of the manufacturer's business, while the user aspires value in relation to the performance of a product. The user has no interest in volume, but with the traditional working principle of the business model, a larger sold volume adds to the aspired value of profitability of the manufacturer. In the case of Take Back Chemicals, the working principle of the business model both leads to a profitable business for the manufacturer, and a high performance per chemical for the user. In this way, the explained artifact frames of the manufacturer and the user are related in accordance to compatibility level 5, which implies dissolving issues of integration, and can lead to a state of abundance for the relation between different forms of aspired value.

Figure 64 presents the schemes of the levels of compatibility of a traditional business model in comparison to the business model of Take Back Chemicals. For the traditional solution, an overall artifact frame in which a feasible value for the user and the manufacturer is obtained is possible in the case of compatibility level 2. However, then the user and the manufacturer have to come to a compromise. For Take Back Chemicals, both the optimum aspired value for the user and the optimum aspired value for the manufacturer can be obtained simultaneously.■

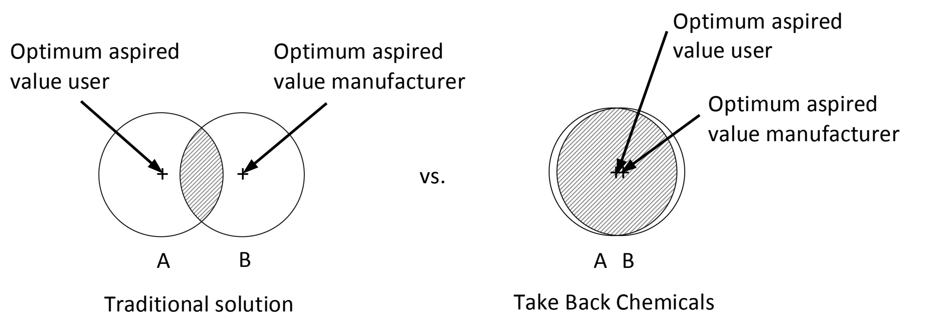


Figure 64 Schemes of the levels of compatibility of a traditional solution (compatibility level 2) versus Take Back Chemicals (compatibility level 5)

The examples of Organica Water and Take Back Chemicals in this section, and the Sand Motor in section 3.3.2 of this dissertation, show that a 'thing' can have different working principles in relation to the forms of aspired value. The working principle in these examples is subordinate to framing. The framing of the working principles can frame the interrelation between different artifact frames, and therewith frame the compatibility of different artifact frames.

Framing Artifact Frames

Regarding the aspired value and the working principles, the framing of these components was already described in this section. The artifact frame is constructed by the aspired value and the working principle(s), and therewith determined by the framing of these two components. When multiple artifact frames are at stake in a context of integrated design, a designer can frame the aspired value and the working principle(s) of multiple artifact frames to obtain a desired level of compatibility. Therefore, first of all the identification of the main system aspects can be translated into the identification of the different artifact frames.

By identifying the different artifact frames, additionally the interrelation and possible incompatibility between different artifact frames can be investigated. The incompatibility between artifact frames is a result of incompatible forms of aspired value and their corresponding working principles. Understanding the main system aspects and the system scope and constraints should therefore also imply an identification of the typology of constraints. A typology of constraints gives an overview of which constraints are subordinate to framing. When constraints are subordinate to framing, the design space for integration can possibly also be (re)framed through a process of co-evolution.

Section 3.2.3 of this dissertation already presented a layered structure of constraints that defines the artifact frame, which was illustrated in Figure 21. Looking for common ground on deeper layers can increase the design space for integrated design and open possibilities for developing artifact frames that are compatible in accordance with compatibility level 5. Searching for common ground as a fundament for integration is therefore a search for common ground in different layers of constraints. This can be investigated for both common ground in forms of aspired value and common ground in working principle(s). The common values that can be defined from this investigation form a fundament for integration. There after, the common values should be accompanied by common working principles that lead to different forms of aspired value. In such a way, integration of different artifact frames in accordance with compatibility level 5 can be created and obtained.

(Re)framing of constraints that define the different forms of aspired value and working principles can (re)frame the compatibility of different artifact frames. (Re)framing is possible when the constraints are self-imposed and in the scope of control of the designer. However, although self-imposed constraints can possibly be (re)framed, self-imposed constraints can be so severe and embedded in a paradigm that these constraints almost become intrinsic of character. In many cases, these self-imposed constraints refer to institutionalized structures, which appear in for example procedures, standards, performance indicators, business models, and specific techniques or methods. Paradoxically, in such cases methodological structures can also support becoming aware and overcoming these self-imposed constraints by increasing the design space in integrated design to create more opportunities to obtain compatibility level 5. Designer framing to obtain compatibility level 5 can be an iterative process. In this iterative process, the definition of the aspired value and corresponding working principle(s) are developed through co-evolution. Section 5.3.2 elaborates on the definition of the methodological structure for the framing of different artifact frames in order to obtain compatibility level 5.

5.3.2 A Methodological Structure for the Act of Design

In section 5.3.1, the key elements of the common ground in methodological structures of integrated design approaches were translated into the terminology of chapter 2. From this translation, a meta-method for integrated design is developed and presented in this section 5.3.2. The meta-method should support the conceptual approach that was developed and presented in chapter 3.

Meta-Method Design Steps

In the context of the conceptual approach of chapter 3, first of all can be said that the relation between 'integrated design' and 'compatibility level 5' refers to an act of design. Both the relations between 'compatibility level 5' and 'dissolution', and 'dissolution' and 'abundance' follow from this act of design. The focus for developing a methodological structure for integrated design is therefore on the design steps that refer to relation between 'integrated design' and 'compatibility level 5', which is marked in green in the scheme of the conceptual approach in Figure 65.

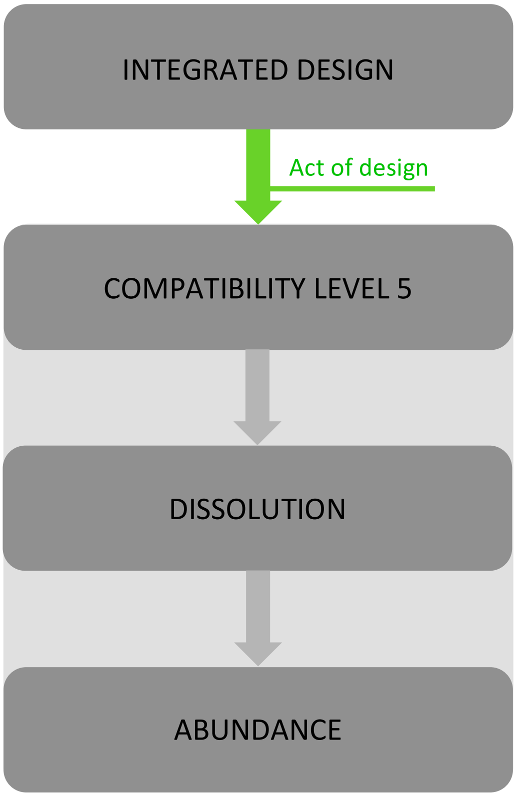


Figure 65 The relation between 'integrated design' and 'compatibility level 5' refers to the act of design in the conceptual approach

Corresponding to the act of design in the conceptual approach, Table 10 presents the main design phases and design steps of the meta-method for integrated design. The main design phases and design steps are derived from the common ground in methodological structures of the integrated design approaches. Although the common ground in design approaches presented three main phases with six design steps in Table 9, the design steps 'reflecting on design' and 'preparing for implementation' in the main design phase 'translating design into implementation' are also common in more traditional design approaches. However, the meta-method for integrated design is intended to apply complementary to currently applied methodological structures in different fields of design in order to dissolve issues of integration. Therefore, the meta-method is formed by the first two main design phases and corresponding design steps as formulated in Table 9. In this way, the meta-method for integrated design can be applied during the design process in cases of issues of integration in complementary to the applied methodological structures of the designer in his/her own design field.

Table 10 Meta-method consisting of main design phases and design steps for the act of design in the conceptual approach

Meta-method	
Main design phases	**Design steps**
Frame awareness (Understanding the system in its context)	1) **Identifying different artifact frames** (Identifying main system aspects)
	2) **Identifying a typology of constraints** (Understanding main system aspects in relation to system scope and constraints)
Designer framing (Synthesizing)	3) **Translating aspired value into values** (Searching for common ground as a fundament for integration)
	4) **Defining common working principles and forms of aspired value** (Deepening and structuring of the fundament for integration)

The key elements of the common ground in methodological structures of integrated design approaches were translated into the terminology of chapter 2 in section 5.3.1. In chapter 2, 'integrated design' was described as the 'framing of the compatibility of multiple artifact frames'. In this terminology, the different design phases for integrated design are differentiated in 'frame awareness' and 'designer framing', which are differentiated in four design steps. A brief elaboration of the design steps for the act of design between 'integrated design' and 'compatibility level 5' is given from this point:

<u>**Frame awareness:**</u>

Step 1: Identifying different artifact frames, as structures of constraints

An artifact frame is constructed of an aspired value and a working principle. To identify different artifact frames in a context of multiple stakeholders, the designer should identify the artifact frame per stakeholder. This investigation will give an overview of the relation between the defined forms of aspired value and corresponding working principles. In addition, a designer has to be aware of the relativity of value. For example, from a stakeholder frame, people can aspire a different value than their personal aspired value. This difference in role should be clearly defined in the investigation of frames. A designer should in the context of a design challenge focus on the defined aspired value in relation to a stakeholder frame. Another aspect to be aware of is that the same absolute value can be perceived in the different ways. The perception of value should therefore be distinguished from the absolute value in the definition of the aspired value. At last should also be taken into account that the definitions of 'cost' and 'value' are frame dependent and that frames can possibly change over time

Step 2: Identifying typology of constraints, from intrinsic to self-imposed constraints

After the investigation of the artifact frames, as structures of constraints, in addition the typology of the different constraints that are related to issues of integration can be investigated. Some constraints will be in the scope of control of the designer and some constraints out of the scope of control of the designer, along a spectrum from intrinsic to self-imposed. When the constraints are in the scope of control of the designer, the designer is in a position to (re)frame these constraints in order to increase the design space in the case of incompatible artifact frames. The design steps that are related to frame awareness give the designer an overview of the artifact frames, with a typology of constraints, and necessities and opportunities to (re)frame the structure of constraints for integration

<u>**Designer framing:**</u>

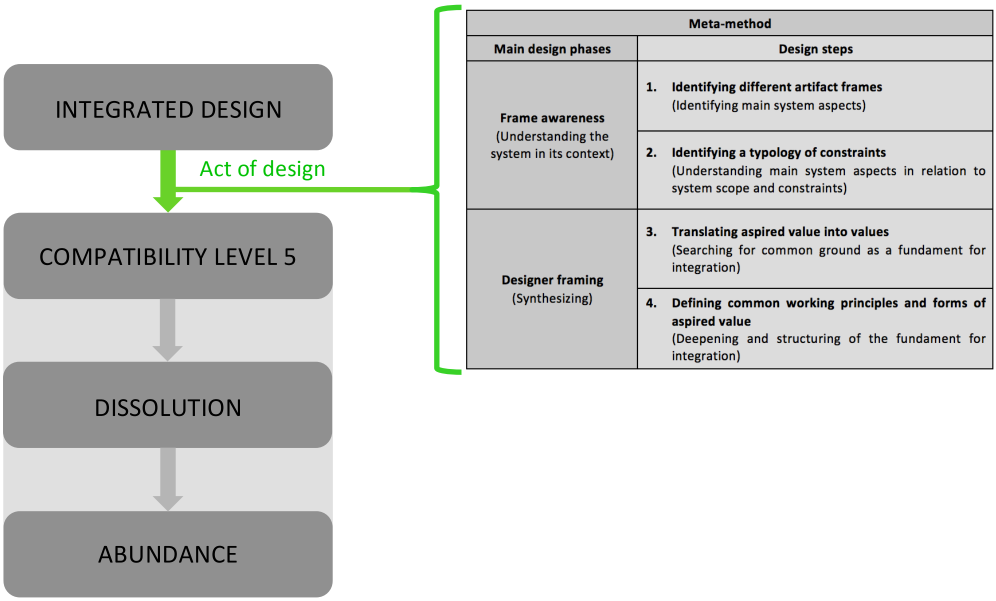
Step 3: Translating aspired value into values

When the necessities and opportunities for framing are investigated, a designer can try to dissolve incompatibility through first searching for common values. In some cases, different forms of aspired value, as part of a defined artifact frame, are incompatible, although the values, were the different forms of aspired value are based on, are not incompatible. Through a process of co-evolution, a designer will search for common values, which form a fundament for integration

Step 4: Defining common working principles and forms of aspired value

The aspired value and corresponding working principles together construct the artifact frame. In a setting of multiple stakeholders and corresponding artifact frames, a designer will try to design common working principles that lead to different forms of aspired value without the necessity for value trade-offs and the exchange of capital. The forms of aspired value are (re)defined in relation to the design of common working principles. A designer will strive, through a process of co-evolution, for artifact frames that are integrated in accordance with compatibility level 5. The process of co-evolution should lead to a design space in which issues of integration can be dissolved through design, and different forms of aspired value can obtain a state of abundance in relation to each other

The relation between the act of design in the conceptual framework, and the meta-method for integrated design that is presented in Table 10, is given in Figure 66. The two main design phases and the four design steps form the methodological structure for the act of design.



Meta-method	
Main design phases	**Design steps**
Frame awareness (Understanding the system in its context)	**1. Identifying different artifact frames** (Identifying main system aspects)
	2. Identifying a typology of constraints (Understanding main system aspects in relation to system scope and constraints)
Designer framing (Synthesizing)	**3. Translating aspired value into values** (Searching for common ground as a fundament for integration)
	4. Defining common working principles and forms of aspired value (Deepening and structuring of the fundament for integration)

Figure 66 The main design phases and corresponding design steps as the methodological structure for the act of design in the conceptual approach

Meta-Method Design Process Model

The meta-method design steps already show a sequential structure of process in their order. In addition, these design steps, which were summarized in Table 10, can be related to scheme of the design process in Figure 58.

The four identified meta-method design steps correspond to divergence and convergence in relation to respectively the definition of the problem or opportunity space, and the definition of the solution space. In terms of framing refers the definition of the problem or opportunity space to frame awareness, and the definition of the solution space to designer framing. Figure 67 shows a scheme of the meta-method design steps and phases in relation to the structure of divergence and convergence in the development of an integrated design.

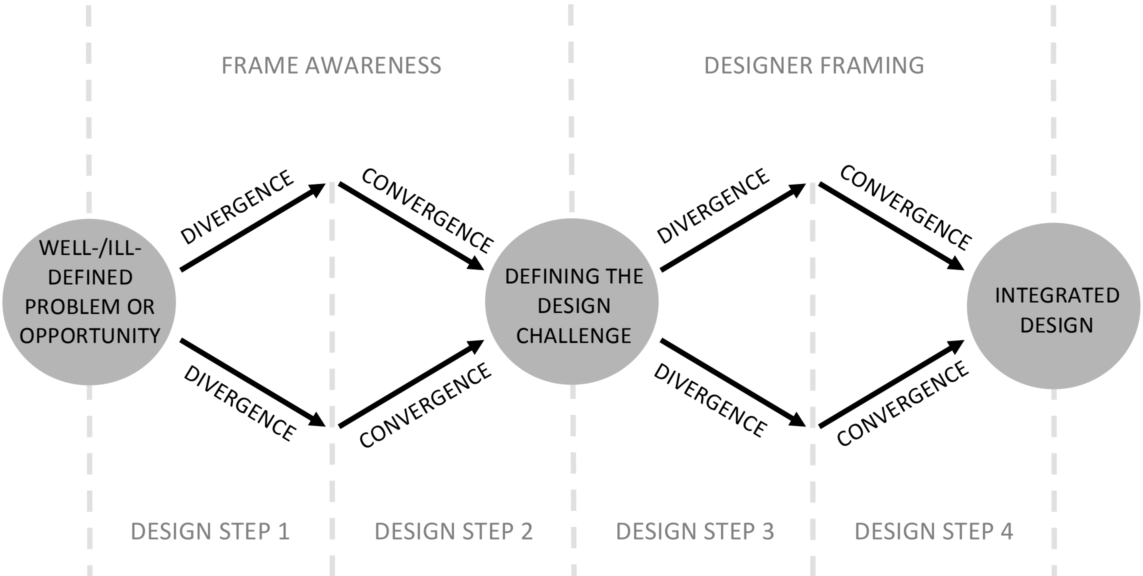


Figure 67 Meta-method design steps and phases as part of the design process for the act of design in the conceptual approach

A scheme of the design process model of the meta-method to support the development of integration in accordance with compatibility level 5 is given in Figure 68. The design process model of the meta-method contains the main design phases and corresponding design steps that are obtained from the translation of the key elements of the common ground in methodological structures of integrated design approaches. The design process model refers to the act of design in the conceptual approach. The feedback loops within and between the design steps refer to the co-evolutionary and short cyclic iterative character of the integrated design process.

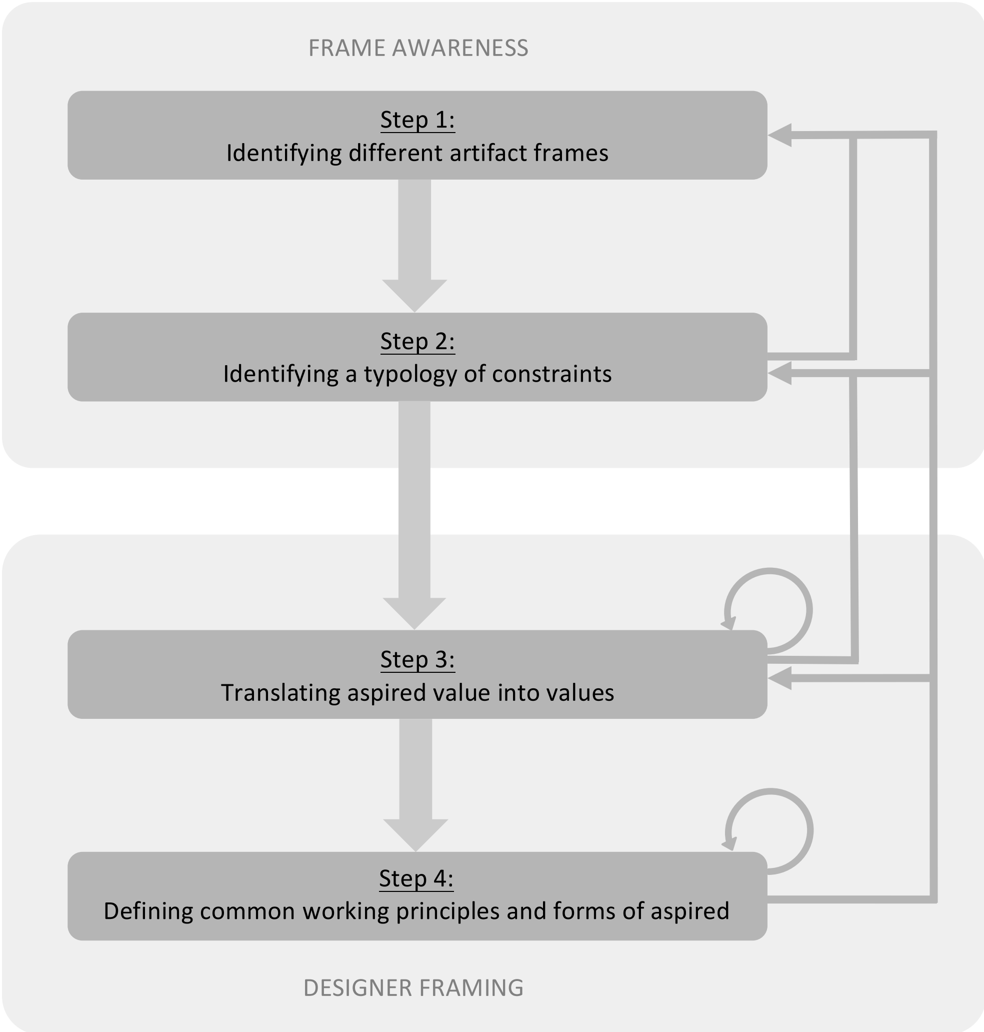


Figure 68 Design process model of the meta-method for the act of design in the conceptual approach

5.4 Conclusions

In chapter 3, a conceptual approach for integrated design was developed. Subsequently, chapter 5 is about the development of a meta-method for the conceptual approach of chapter 3. Chapter 5 is related to research question 4 and sub-questions 4.1 and 4.2, which are formulated as:

Research question 4:	How can a meta-method for integrated design support solving issues of integration?
Sub-question 4.1:	What are the key elements of the common ground in methodological structures of integrated design approaches?
Sub-question 4.2:	How can the key elements be translated into a meta-method for integrated design?

To formulate a conclusion with respect to research question 4, sub-questions 4.1 and 4.2 are discussed, before coming back to research question 4.

Sub-question 4.1: What are the key elements of the common ground in methodological structures of integrated design approaches?

The investigation of integrated design approaches shows a differentiation in explicitness and application. However, common ground can be found in the integrated design approaches Building with Nature, Transdisciplinary Design, and Framing. These integrated design approaches contain design steps and design phases that represent their methodological structures. The common design phases with corresponding design steps for the integrated design approaches can be described as:

Understanding the system in its context:
1) Identifying main system aspects
2) Understanding main systems aspects in relation to system scope and constraints

Synthesizing:
3) Searching for common ground as a fundament for integration
4) Deepening and structuring of the fundament for integration

Translating design into implementation:
5) Reflecting on design
6) Preparing for implementation

From this investigation can be concluded that these six design steps and corresponding design phases can be distinguished as key elements of the common ground in methodological structure of the investigated integrated design approaches. The first four design steps represent a process of divergence and convergence in order to find a common ground as a fundament for integration through design. The fifth and the sixth design step refer to translating design into implementation and are also common in more traditional design approaches.

Sub-question 4.2: ***How can the key elements be translated into a meta-method for integrated design?***

First of all should be taken into account that the meta-method refers to the act of design in the conceptual approach. The act of design is the relation between 'integrated design' and 'compatibility level 5'. 'Dissolution' and 'abundance' follow from the act of design between 'integrated design' and 'compatibility level 5'. In chapter 2, 'integrated design' was defined as the 'framing of the compatibility of multiple artifact frames'. The artifact frame was described as the construction of the aspired value and the working principle(s). Therefore, the framing of the compatibility of multiple artifact frames is subordinate to the framing of the aspired value and the working principle(s).

In the terminology of framing, the understanding of the system in its context is predominantly about the identification of the artifact frames and the identification of which constraints are subordinate to (re)framing. These design steps are part of a phase of frame awareness. For the framing of the aspired value holds the principle that people's valuation is 'reference state dependent'. The perceived value is determined by the interplay of 'observation' and 'context'. Framing of 'observation' and 'context' can lead to different perspectives on value and different definitions of the aspired value. Although different forms of aspired value and corresponding working principles can be conflicting, underlying values do not have to conflict. The search for common ground as a fundament for integration is therefore about translating different forms of aspired value into common values.

Subsequently, the deepening and structuring of the fundament for integration is related to defining common working principles and forms of aspired value. The working principles are developed in relation to the common values, where after the forms of aspired value per stakeholder can be (re)defined. The translation of forms of aspired value into common values as a fundament for integration, and the following definition of common working principles and forms of aspired value, are part of a phase of designer framing.

The translated design phases and design steps that represent a meta-method for the act of design in the conceptual approach are formulated as:

Frame awareness:

1) Identifying different artifact frames
2) Identifying a typology of constraints

Designer framing:

3) Translating aspired value into values
4) Defining common working principles and forms of aspired value

The feedback loops within and between the design steps refer to the co-evolutionary and short cyclic iterative character of the integrated design process.

Research question 4: ***How can a meta-method for integrated design support solving issues of integration?***

When incompatible artifact frames cause issues of integration, a designer can use the meta-method to identify the artifact frames and their typology of constraints. In this way, the designer can increase frame awareness and identify opportunities to frame different forms of aspired value and corresponding working principles. Additionally, the meta-method also supports the search for, and definition of common values. Forms of aspired value can conflict, but underlying values do not have to conflict. From common values, working principles and forms of aspired value can be (re)defined through a process of co-evolution. The meta-method methodologically structures the design process of divergence and convergence, in order to find and define a common ground for integration, and to obtain compatibility level 5 for the relation between different artifact frames. The integrated design process is a co-evolutionary and short cyclic iterative process, with feedback loops within and between the design steps. The translated design phases and design steps that represent a meta-method for the act of design in the conceptual approach are formulated as:

Frame awareness:

1) Identifying different artifact frames
2) Identifying a typology of constraints

Designer framing:

3) Translating aspired value into values
4) Defining common working principles and forms of aspired value

The meta-method can be used by designers in different disciplines, for different fields of application, to support solving issues of integration. In addition, the meta-method can be used to develop an integrated design approach for a particular field of application. Finally, it also forms a platform for discussing methodological structures for integrated design with respect to the act of design in the conceptual approach. The meta-method for integrated design is not intended to replace currently used methodological structures in different fields of design, but as an additional method that can be used in parallel to support solving issues of integration.

6 Integrated Design in Practice

6.1 Introduction

Chapters 2 to 5 described the theoretical framework for integrated design. Chapter 2 was about a definition of integrated design and a terminological fundament was developed for discussion and the sequence of this research. This continued in chapter 3 with the presentation of a conceptual approach for the research question how integrated design can support solving issues of integration. These issues of integration were in chapter 1 already described as 'issues derived from defined problems' and 'issues derived from the lack of opportunities to incorporate value'. Therewith, chapter 3 described for which 'end', integrated design is the 'means'. Together, chapter 2 and chapter 3 form the semantic framework for integrated design.

In chapter 4, the relation between the applied methodological structures for design and the definition of the design space for different faculties at Delft University of Technology was at stake. Chapter 4 showed first of all that this methodological structuring is deeply embedded in modes of reasoning in design over time. In addition, chapter 4 showed how the choice for a methodological structure frames modes of reasoning in design and correspondingly perspectives on integrated design.

Chapter 5 added to chapter 4 a methodological structure for a meta-method for integrated design that can serve as a fundament for methodological discussion and development. Chapter 5 built on the terminological common ground from chapter 2 and the conceptual approach as developed in chapter 3. Chapter 4 described the relation between methodological structure and the definition of the design space, and therewith described the framing process with respect to integrated design. Together, chapter 4 and chapter 5 form the methodological framework for integrated design.

In addition to the theoretical research into integrated design of chapters 2 to 5, this dissertation also incorporates research into integrated design in practice in this chapter 6. The foregoing description of the aim of the chapters 2 to 5 illustrates a fundament for theoretical discussion and development. However, a description of integrated design in practice adds another perspective on integrated design in addition to the theoretical discussion and development. Also, the main findings from integrated design in practice can be reflected on the theoretical framework for integrated design. Together, the theoretical framework and the research into the main findings from integrated design in practice form the larger framework for integrated design, as was already schematized in Figure 4 in section 1.4.

Chapter 6 is related to research question 5 and corresponding sub-questions 5.1, 5.2, and 5.3. Research question 5 and sub-questions 5.1, 5.2, and 5.3 are in this context formulated as:

Research question 5:	What are the main findings from integrated design in practice?
Sub-question 5.1:	What is the motivation for integration?
Sub-question 5.2:	Which design aspects determine how the design is integrated?
Sub-question 5.3:	What are the conditions for the integrated design process?

The aim of chapter 5 is to describe the main findings from integrated design in practice. Sub-question 5.1, 5.2, and 5.3 add in this context respectively a perspective why the choice was made for this explicit integration of functions, a perspective what the final integrated design comprehends and which design choices were made for what reason, and a perspective which conditions were necessary, limiting, or created to come to the integrated design solutions. These three perspectives construct the findings from integrated design in practice.

For this research, cases are selected that were recognized and rewarded by public and expert juries for their integrated designs. The selected cases for the research in this chapter 6 are in short:

- Coast Katwijk, Katwijk
  In Katwijk, the reinforcement of the primary sea defense is integrated with the facility of an underground parking garage. This project is constructed at the edge of the City of Katwijk and redefines the relation between the city and the sea

- Benthemplein, Rotterdam
  At Bethemplein in Rotterdam, the redevelopment and upgrade of the public space on the square is integrated with facilities for water buffering

- Biomakery Strijp-S, Eindhoven
  The formerly industrial area Strijp-S is transformed to a new modern neighborhood where wastewater treatment will be processed locally. The innovative concept of the Biomakery creates opportunities to integrate wastewater treatment with dense urban living

The three cases are all water related, although related to different water domains such as respectively flood risk reduction, water buffering, and wastewater treatment. The relation of the cases with water was not a selection criterion on beforehand, but appeared to be the case when looking for cases of integrated design in practice. Apparently, integrated design in relation to water is, at least in The Netherlands, a necessary or appealing practice. The different cases explicitly differentiate in their chronology. Project Benthemplein was completed in 2013 and is already in the phase that an evaluation can be made with respect to for example maintenance and control over time. Project Coast Katwijk was completed in 2015, so the description of a first look at the project can be given, but a complete evaluation of the performance of the design over time is still under development. Finally, project Biomakery Strijp-S is still in the preliminary process of determining the feasibility of the project to obtain governance agreement. The chronological differentiation of the projects can add an extra dimension to the main findings from integrated design in practice. However, the chronology is not leading in the order of description of the different cases. The cases are described in order of research, which means first case Coast Katwijk, thereafter case Benthemplein, and finally case Biomakery Strijp-S. The cases are described along three mains topics a), b), and c), which correspond with respectively sub-questions 5.1, 5.2, and 5.3. Topics a), b), and c) are formulated as:

a) Motivation for integration
Description of project background and integration context

b) Design aspects in relation to integration
Description of design aspects that determine how the design is integrated

c) Conditions for the integrated design process
Description of the conditions for the integrated design process to obtain integrated design solutions

The selected cases are researched through project documents and interviews. The interviews are organized as open interviews, in which the already described topics 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process' will come along during the interview. Open interviews with defined topics to discuss are chosen to serve the exploratory character of this research into integrated design. In addition, interviewees in different complementary roles in relation to the case were chosen to obtain different perspectives. The interviewees project roles are presented in Appendix B. In Appendix B, and in this dissertation from this point, the interviewees are indicated by their case and interviewee number: interviewee (case number.interviewee number) = interviewee (c.i). The coding schemes of the transcribed interviews can be found in Appendix C.

Sections 6.2, 6.3, and 6.4 are about the description, analysis, and definition of themes of respectively Coast Katwijk, Benthemplein, and Biomakery Strijp-S. In addition, these sections also contain the reflection on the cases from a theoretical perspective, as developed in the theoretical framework. The threefold structure a), b), and c), which corresponds with respectively sub-question 5.1, 5.2, and 5.3, forms also the structure for the description of the different cases in section 6.2, 6.3, and 6.4. Section 6.5 contains the cross-case analysis. Finally, section 6.6 contains the conclusions with respect to research question 5 and sub-questions 5.1, 5.2, and 5.3.

6.2 Case: Coast Katwijk

6.2.1 Case Description and Analysis

Clients:	Regional Water Authority of Rijnland Municipality of Katwijk
Design:	Arcadis (structural design) Royal HaskoningDHV (parking garage and spatial design surface level) OKRA (landscape design)
Location:	Katwijk
Project status:	Completed in 2015
Site area:	1.800.000 sqm
Parking capacity:	663 parking lots
Cost:	Parking garage 16 million euro Water defense 25 million euro Spatial facilities 6 million euro

a) Motivation for integration

The initiation for project Coast Katwijk started as part of a larger program, namely the 'Hoogwaterbeschermingsprogramma'. As part of this program, Katwijk was named as a weak point in the primary sea defense, which meant that Katwijk had to be reinforced in order to meet the flood risk norm of 1/10.000 years, as stated by Arcadis (2013a). However, although the coastline at Katwijk had to be reinforced, Katwijk was not a priority project of this program. Other nearby places, such as Noordwijk and Scheveningen, were prioritized in terms of necessity above Katwijk.

The reinforcement of the coastline at the City of Katwijk would mean that the parking facilities at the boulevard would get lost, because of the larger space necessary for the reinforcement. The position as a non-priority location gave Katwijk the opportunity to see the results of reinforcement projects in comparable cases such as Noordwijk and Scheveningen. The redesign of the boulevard reduced the number of parking lots in Scheveningen with 400 in total. In Noordwijk, the issue of parking space was also part of the case, and they think therefore at the moment about connecting the beach and parking space by shuttle bus services. In addition, Noordwijk was confronted with problems of higher ground water levels due to the seawards supplementation of sand, as interviewee (1.4) explains.

The experiences in reference project such as Scheveningen en Noordwijk gave the non-priority location Katwijk the opportunity to overthink their own case. Reinforcement of the weak point in the coastal defense at Katwijk would reduce the number of parking lots. However, the reinforcement of the coastline was necessary from the perspective of flood risk reduction. This conflict or paradox in interests regarding the use of space was a starting point for the development and design of a solution for Katwijk. In a broader context, there was also a notion of the increasing space required for flood risk reduction measures in combination with the little amount of space in the Netherlands. Therefore, the project was also motivated by the ambition to start to combine functions due to the lack of space, as interviewee (1.1) explains. The situation in Katwijk was that a part of the City of Katwijk was positioned outside the primary sea defense, as illustrated in Figure 69.

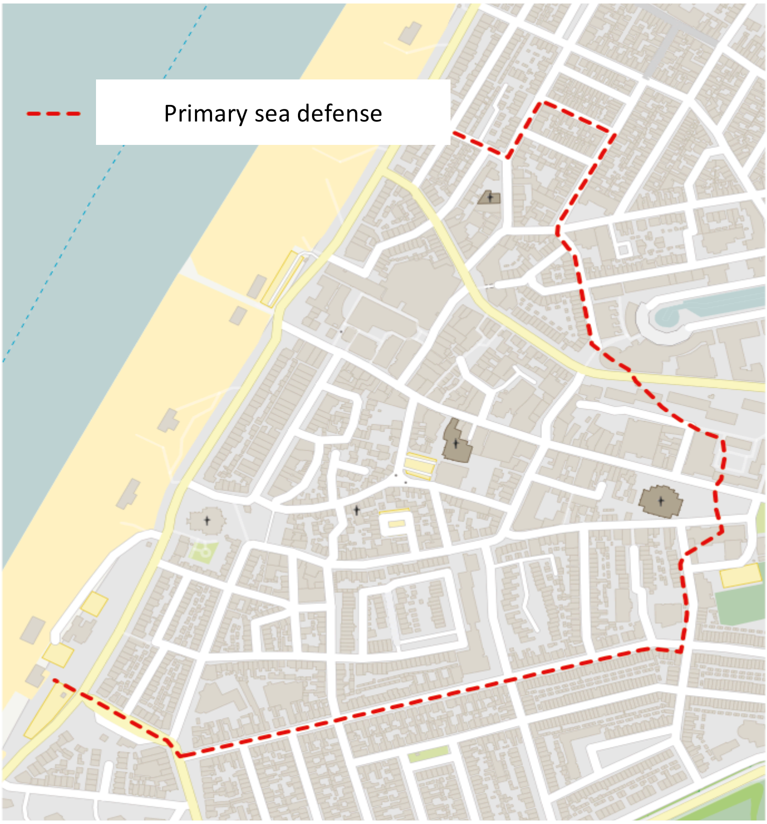


Figure 69 Primary sea defense Katwijk before project Coast Katwijk
Source: [Overview Situation Katwijk] (n.d.)

In addition to the conflict or paradox between coastal reinforcement and the availability of parking space close to the beach, the views of the residents living along the boulevard were also an important factor to take into account. Although the primary sea defense at Katwijk formed a weak point in the total coastline, the residents along the boulevard had the opportunity to overlook the beach and the sea from their home. Therefore, the question was also if this view could be maintained, as interviewee (1.4) explains. The aspects of coastal reinforcement, parking space close to the beach and the shopping area of the City of Katwijk, and the views for the residents along the boulevard formed the main challenge with respect to integration. The spatial challenge to integrate these functions was subordinate to design.

b) *Design aspects in relation to integration*

Dike in dune

The case 'Coast Katwijk' contains multiple integrated design solutions. The issue of integration between the necessary reinforcement of the primary sea defense and the availability of parking space close to the beach and the shopping area of the City of Katwijk was solved through an integrated design for the coastal defense and the parking space. Voorendt (2017) describes the 6 alternatives that were developed in this context. From these 6 alternatives, the 'dike in dune' alternative was chosen as the final design, because through the hard structure of the dike it was possible to construct to maximum +8 meters NAP instead of +10 meters NAP in the case of a 'high sand dune' design. The 'dike in dune' alternative reduces the impact on the residents along the boulevard in terms of views. The hard structure of the dike consists of a sand core, which is covered by concrete blocks on top of a filter layer and geotextile (Voorendt, 2017). The schemes of the 'high dune' and 'dike in dune' alternatives are given in comparison to the original situation before design in Figure 70.

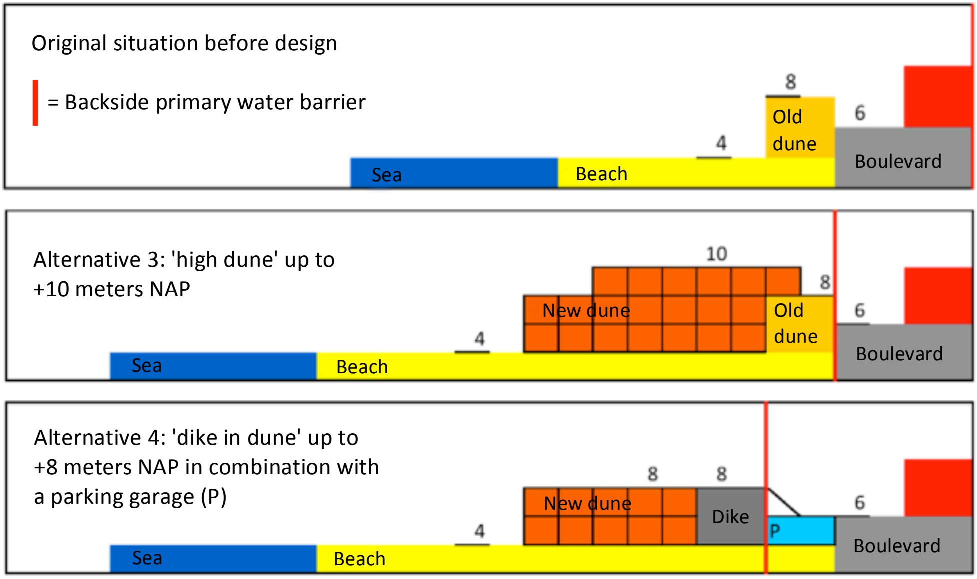


Figure 70 Schemes of alternatives 'high dune' and 'dike in dune' in comparison with the original situation before project Coast Katwijk

Source: H. van Dalfsen (personal communication, July 9, 2019)

Seen from above in, as given in Figure 71, the curved shape of the 'dike in dune' created some space between the boulevard and the hard dike structure. This gave room to construct the parking garage at the landside of the dike. Without the 'dike in dune' structure, the alternative of the reinforcement 'high dune' would have become +10 meters NAP, instead of +8 meters NAP of the 'dike in dune' structure. In addition, the 'high dune' would have required a sand supplementation of 120 meters seawards, instead of the 90 meters seawards for the 'dike in dune'. These 30 meters extra are now used for the parking garage, as interviewee (1.5) and interviewee (1.4) explain. The parking garage contains 663 parking lots. In total, the parking garage has a length of 500 meters, a width of 30 meters, and visitors can leave the parking garage from 7 exits and 4 separate emergency exits (R. van den Brule, personal communication, May 28, 2019). Interviewee (1.2) states that without the integration of the parking garage in the dune, the parking lots would possibly have been constructed at the edges of the City of Katwijk. Therefore, the space that is required for the parking garage could be saved by the 'dike in dune' design. Figure 71 gives an overview of the dike in red, and the space for the parking garage behind this 'dike in dune'.

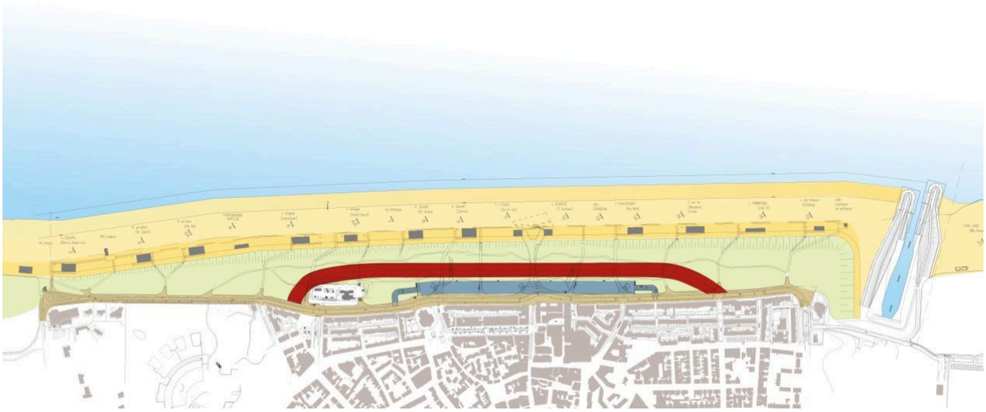


Figure 71 Overview of the dike in red and space for the parking garage behind the 'dike in dune'
Source: Arcadis (2013b)

Although the dike and the parking garage look spatially one on the scale of the dune, the dike and the parking garage are structurally separated. Alternatives to integrate the structure of the parking garage with the structure of the primary sea defense were rejected by the Regional Water Authority of Rijnland for several reasons. First of all, the parking garage was not the main responsibility and ambition of the Regional Water Authority of Rijnland, as interviewee (1.5) explains. The parking garage was the desire of the Municipality of Katwijk. Integration of both systems would introduce complexity with respect to maintenance and control and funding. In addition, as interviewee (1.1) explains, the project is unique in its setting and their was not enough knowledge about the technical lifespan of the concrete wall.

Interviewee (1.1) formulates it as follows:

> *'However, the main point is that sand has a certain eternal value. Sand that is at the beach, or in the sea does not matter for the water barrier. For the concrete it is harder to say if the concrete still has the structural strength in a hundred years from now. Those a very hard maintenance challenges. Maintenance needs on its turn a testing framework, and what would be the testing framework in that case? That is hard to combine'*

The separation of the dike and parking garage in the design of Coast Katwijk is defined by different institutional responsibilities. The Regional Water Authority of Rijnland is responsible for primary sea defense and the Municipality of Katwijk is responsible for the parking garage. The Municipality of Katwijk bought the land at the landside between the dike and the boulevard, and is the exploiter of the parking garage. The maintenance of the parking garage is also the responsibility of the Municipality of Katwijk.

The Regional Water Authority of Rijnland is responsible for the maintenance of the dike. The separation of the dike and the parking garage is beneficial in terms of maintenance, because of the difference in maintenance cycles of the two elements, as interviewee (1.4) explains.

As part of the responsibility for maintenance and control, the integration of the dike and the parking garage was also determined by the lifespan and necessity for adaptation of both systems. For example, a possible increase in sea level, modeled over 50 years time, can lead to a necessary upgrade of the coastal defense system in the future. To create opportunities for a possible increase of the dike, the dike is designed with a wider profile and a flat top, as Figure 72 shows the cross-section of the dike and its position in relation to the parking garage. The flat top of the dike gives possibilities to increase the height of the dike when necessary. The increase of the dike height can be executed by taking off the top layer of the sand dune. The design of the parking garage will not be affected by a possible increase in height of the dike or by its construction.

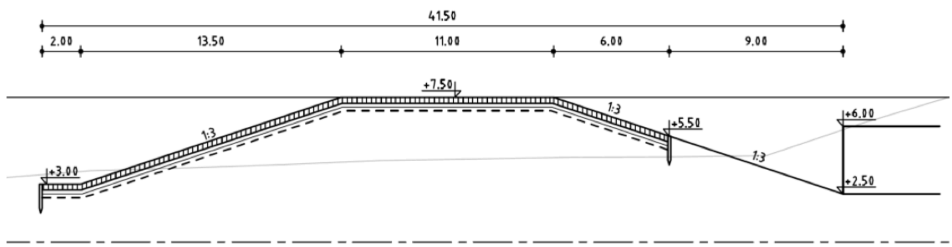


Figure 72 The flat top of the dike gives opportunities to increase the height of the dike in the case of sea level rise
Source: Arcadis (2013c)

For the parking garage holds that it does not have opportunities to adapt, except from intervention through heavy construction effort, as interviewee (1.1) explains. This was also a choice that was made on the base of cost efficiency. The possibility to adapt for the primary sea defense is more stringent than the possibility to adapt for the parking garage. Therewith, in addition to a difference in maintenance cycles, the dike and parking garage also differ with respect to the interest of possibilities for adaptation.

In the context of funding, a similar structure of a clear separation in institutional responsibilities can be observed. Although the dike and parking garage can structurally be described as separated elements, the funding for the project was part of one tender. The Municipality of Katwijk and the Regional Water Authority of Rijnland worked together on one tender for the whole project. The contractor would have 2 clients in that case. To structure this process of tendering, a distribution code for was made for the distribution of the construction costs. For example, for the part of the construction that can be directed to the coastal defense system, the distribution code prescribed a distribution of 87 percent funding by the Regional Water Authority of Rijnland and 13 percent by the Municipality of Katwijk. For the construction of the spatial design on the dune, a distribution of the costs of 67 percent for the Regional Water Authority of Rijnland, and 33 percent for the Municipality of Katwijk was made. The costs of the parking garage were 100 percent directed to the Municipality of Katwijk. Along the distribution codes for different elements, the invoices of the contractor were split during the construction process. Interviewee (1.4) explains that all the distribution codes were secured in agreements before the start of the tender phase.

The different institutional responsibilities defined in this way also the design choices with respect to integration. Because of the clear separation in responsibilities and interests between the different stakeholders, the primary sea defense and the parking garage were designed structurally independent. A structural integration of both primary sea defense and the parking garage would have been too much. Interviewee (1.4) says about this step in the process:

> *'....the step to let go the original policy by Rijnland was already a big step. Another step to use the parking garage as part of the dike structure, this was too much. You can also question if this was desirable, because what do you win with this? You would not reduce the costs that much'*

This quote of interviewee (1.4) emphasizes the notion that the design aspect and scale level from the motivation are leading for the aspired integration in this case. In addition, the scale level and design aspect should be relevant with respect what you can win with it. For Coast Katwijk, the motivation for this project was formed by the desire to integrate the space required for parking and flood risk reduction. The scale level of the dune is in this case the scale level for spatial integration.

Figure 73 shows a moment in the construction process in which the dike is already covered by sand, while the parking garage is still under construction behind the dike structure. Figure 73 illustrates the separated systems and construction with respect to the primary sea defense and the parking garage.

Figure 73 The concrete parking garage still uncovered by sand during construction
Source: [The Parking Garage Under Construction] (n.d.)

In the case of Coast Katwijk the spatial aspect was the main motivation for integration. The largest gain in spatial integration in the generated alternatives was to design the parking garage at the landside of a hard dike. A structural integration of for example the seaside wall of the parking garage with the primary sea defense would have created additional parking space, but this was not necessary because of the space in North and South direction as interviewee (1.4) explains. This was neither desirable in combination with the implications of structural integration of the parking garage and the primary sea defense. Thereby, the creation of additional space by structurally integrating the parking garage and the primary sea defense would have been marginal with respect to the total amount of created space for parking. The case Coast Katwijk therewith also illustrates that a certain type of integration should not be a goal in itself, but related to the scale level and aspect of motivation of the aspired value, which is in this case the gain of multi-functional space at the scale level of the dune.

Emergency exits and the walking paths on the dune
The parking garage also requires emergency exits, which come at ground level in the dune landscape. Therefore, the designers made a spatial plan for these emergency exits. However, the emergency exists should also be accessible by the fire brigade and hard layer paths towards the emergency exits and parallel to the boulevard are necessary from that perspective. While from the norms in the policy of the Regional Water Authority of Rijnland, hard paths on top of the dune system are not allowed due to the possibility of negatively interrupting the natural sand supplementation by the wind. However, in the

situation of Katwijk, an exception from their policy was already made when the former Queen visited the City of Katwijk on Queensday. For this event, a dune path parallel to the boulevard was already applied. Therefore, again the policy of Rijnland was adjusted to create room for paths to get access to the emergency exits, as interview (1.4) explains. Interviewee (1.1) states that also the question came up what a hard path actually is, if this is pavement, or softer material as well. In the design, eventually shell paths were sufficient as a hard layer to reach the emergency exits. Figure 74 shows an aerial view for the situation after the construction of the final design.

Figure 74 Aerial view of project Coast Katwijk with the walking paths on the dune parallel to the boulevard
Source: R. van den Brule (personal communication, May 28, 2019)

The integration of the parking garage and the 'dike in dune' in front of the City of Katwijk also forms the entrance to the City of Katwijk for people that arrive by car and park their car in the parking garage. Therefore, the parking garage was also designed in such a way that it could serve as a representative first impression of Katwijk. The collage of Figure 75 gives an impression of the quality of the detail design, such as the parking garage entrances and exits, staircases and emergency exits. The integration of the parking garage created the necessity or opportunity for a high quality spatial design.

Figure 75 Impression of quality of design details with respect to the parking garage
Source: R. van den Brule (personal communication, May 28, 2019)

North and South extension

Although the level of detail in the preparation, the project was open for participation of stakeholders. However, there was a very clear structure of participation. Interviewee (1.5) explains that at a certain moment they communicated very clearly that something had to be done with respect to the coastal reinforcement and that there was a moment in the procedure in which people could express their desires in relation to the design and development. After this moment, the procedure was closed. For the project team this meant a new milestone in the process. Because of the open and clear communication and information of the project team, the amount of objections was very low. In contrast, some residents asked for investigation of lowering the Southern dune next to the boulevard to create a view for the local residents. Initially, the 'dike in dune' design was designed for only the weakest point in the primary sea defense in front of Katwijk. The boulevard is at +6 meters NAP and the dune body in front had a gradual slope downwards to the seashore. However, in the North and the South part of the boulevard, the dune was higher due to sand supplementation by the wind and the project scope was initially not encompassing the North and South part of the boulevard. Then, residents living along the boulevard at the North and the South part asked to incorporate these parts in the design, as told by interviewee (1.4).

In addition, interviewee (1.5) said about the involvement of the residents at one of the reflection sessions:

> *'So, at one of the reflection sessions, one of the residents proposed to calculate if the amount of sand at the Southern part could be constructed lower, in such a way that you could also see the sea from the boulevard. Now there is a view from this side as well. We tried to do everything we said we would do. Every question will be answered within the shortest time possible. And what you say, you do....'*
>
> *'....That was purely something a resident proposed on an open evening. That was very valuable. He said: you already have the equipment there; you cannot tell me that this is not possible. And I think it cost about 50.000 euros in the end. It brought a lot of goodwill'*

The goodwill was necessary because the construction would mean intervention in the living area, where they already lived for years. Other stakeholders, such as the beach club owners were compensated for their periodic loss in income explains interviewee (1.5). In the end, the height of the sand dune in front of the boulevard was decreased, and the span of the dike along the coast was increased in Northern and Southern direction. This also increased the space for alternative positioning of the parking garage behind the dike.

Parking garage entrances and position of houses
For the design of the entrances and exits of the parking garage is taken into account that the residents should perceive as less hindrance as possible from the car lights shining into their property. To assure a minimum hindrance, the entrances and exits are therefore positioned in North-South direction with a curved road that leads to a part of the road along the boulevard. In addition, these roads from the entrances and exits of the parking garage are leading to a part of the boulevard that does not contain houses at the other side of the crossing, but for example a road. Possible car lights shine into a street instead of a house in this case, which causes, as interviewee (1.2) explains, less hindrance for the residents along the boulevard. Figure 76 shows the situation of the driveway to the entrances and exits of the parking garage in relation to the houses along the boulevard.

Figure 76 Entrances and exits of the parking garage parallel to the boulevard and driveway positioned between houses
Source: Visser (2019) (Author)

Drainage system and pavement in parking garage
The drainage system underneath the parking garage is designed to reduce the bulging pressure of the ground water level when increasing the wide of the coastal defense system in seawards direction. To maintain access to the drainage system, a pavement floor is constructed in the parking garage, as presented in Figure 77. Interviewee (1.1) explains that this also created the possibility to leave out a waterproof concrete floor in the design of the parking garage, which reduced the cost of constructing the parking garage.

Figure 77 Pavement floor in the parking garage to maintain access to the drainage system underneath
Source: R. van den Brule (personal communication, May 28, 2019)

c) Conditions for the integrated design process

Original alternative created space for integration

The momentum for the integration of the 'dike in dune' and the parking garage was formed by the already planned intervention of the Regional Water Authority of Rijnland as part of the 'Hoogwaterbeschermingsprogramma'. The regional water authority originally calculated with a, as interviewees (1.1), (1.2), (1.4), and (1.5) call, 'sober and effective' design. This implied the choice for a traditional design of a 'high sand dune'. However, when the Municipality of Katwijk wanted to integrate a parking garage in the primary sea defense, different types of alternatives had to be developed. The 'high sand dune' required as already described a sand supplementation of 120 meters seawards, instead of the 90 meters seawards for the 'dike in dune'. The Regional Water Authority of Rijnland was willing to still calculate with the 120 meters seawards in the 'sober and effective' alternative of the 'high sand dune'. This was also reserved in the project budget as part of the 'Hoogwaterbeschermingsprogramma'. The Municipality of Katwijk could in that case use the 30 meters extra space for a parking garage.

It can be said that the required space for the parking garage appealed to an already existing alternative for design and therewith links to a larger scale program. In this way, the Regional Water Authority of Rijnland did not have to deviate from their original intervention plans, which created a momentum for the Municipality of Katwijk to use the space between the dike and the boulevard for a parking garage.

Shared ambition and structure for understanding each other's systems

From the interviews with interviewee (1.1) and interviewee (1.4) can be stated that the process was, except from formal governance agreements and evaluations, not documented. However, from the interviews a couple of categories can be defined that form building blocks of conditions for the process of integration. First of all, one of the main conditions for the process of integration are the importance of 'ambitious people' and an 'aligned mindset'. All interviewees refer implicitly or explicitly to the importance of a 'shared ambition' and 'understanding each other's systems', as can be observed in Appendix C.1. Interviewee (1.2) expresses it as:

> *'I think it is people's work. In every project you see that it is about the people. You need people who strive for certain ideas and also act in this way. There are so many integral projects, and everyone has their own interest. In this case, it seemed if everyone had the interest of making something beautiful'*

The 'understanding of each other's systems' was well organized from the beginning of the project. Interviewee (1.5) explains that the team was present at the building site and worked with very short cyclic decision-making. Every member of the building team was present in the meetings once every 2 weeks. This gave room to discuss each other's issues or opportunities for solution, which increased the 'understanding of each other's systems as well'. The project was executed with an 'integral way of working', as named by interviewee (1.1).

Interviewee (1.1) further describes this way of working as:

> *'The integrality is not only in functions, but also integrality with respect to the residents, and integrality with respect to the clients. The different parties all had their own clients, in which they all had their own orders. Arcadis had their own orders, as OKRA and RHDHV had. However, there was the will to collaborate and think together'*

In this so-called 'integral way of working', the 'aligned mindset' can be distinguished again.

Interviewee (1.5) emphasizes the importance of aspects that can be related to 'preparation' of the project. Especially the incorporation of 'capable people' with a lot of experience made that the project was 'well organized from the beginning' and that they wanted to 'prepare in detail for procedures'. With respect to these design choices, the tender process contained also a high level of 'detailed design'. This tender process was built on a high-level detail design to guarantee the intended compatibility and aspired value.

Governance agreement and cost efficient
In addition to the 'soft' aspects, the process also incorporated some 'hard' aspects. First of all 'governance agreement'. In the interviews with interviewees (1.1), (1.4), and (1.5), the governance agreement came forward as a crucial aspect in order to design and develop the aspired integration. In order to obtain an agreement in governance, the Regional Water Authority of Rijnland had to change their policies with respect to the following main points:

- Primary sea defense has possibilities for reinforcement at two sides (interviewee 1.4)
- No hardened walking paths parallel to the boulevard on top of the dunes to maintain natural sand distribution (interviewee 1.4)

The exceptions that were made and affirmed in the governance agreement were based on the investigation of the feasibility studies in relation to different design alternatives. Especially the 'cost efficiency' was a main aspect to determine the feasibility of the project, as stated by all interviewees (1.1), (1.2), (1.3), (1.4), and (1.5). In addition, there was also a 'momentum' for the exceptions of the regional water authority. An extension of the primary sea defense was already bound by the boulevard and the City of Katwijk at the landside. This limited the landside extension and reinforcement of the primary sea defense. For the walking paths on top of the dunes held that there was already an exception made for this when the former Queen of the Netherlands visited Katwijk on Queensday. Interviewee (1.4) told that they made a special walking path for her for this occasion. This exception was now used to get an exception in the project as well.

6.2.2 Themes and Reflection

Section 6.2.1 explained case Coast Katwijk along the different topics 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. These topics came along in the interviews and were coded and categorized. In this section 6.2.2, the codes and categories are related to different themes and sub-themes per investigated topic. Table 11 presents a summarized version of the different themes and sub-themes, without the related codes, categories, and interviewees. The complete table with the relation between interviewees, codes, categories, themes, and sub-themes can be found in Appendix C.1.

Table 11 Themes and sub-themes Coast Katwijk

Case: Coast Katwijk	
Topic: Motivation for integration	
Theme	Sub-theme
The motivation for integration is driven by availabilities and experiences in former projects	The available context creates opportunities for integration
	The lack of space and the experience of conflict in former projects drives the desire for integration
Topic: Design aspects in relation to integration	
Theme	Sub-theme
The aspired integration is context dependent	The aspired value can be defined on different scales
	Hierarchy in functionality
	Different lifecycles drive modularity
	Project responsibilities are defined in line with institutional responsibilities
Topic: Conditions for the integrated design process	
Theme	Sub-theme
Momentum, a creative alternative, and a detail design agreement form the base for integration	Detail agreement secures quality of integration
	The feasibility is determined by a momentum in cost, technology, and programs
An open, active, and collaborative, but strictly structured setting to discuss the integration of different interests	The individual ambition of people is key
	Open interaction and understanding in project team is key
	Very strict project management structure from the beginning is key
	Actively involving stakeholders is key
	No need to document process

The system of Coast Katwijk is schematized on headlines from a design perspective in Figure 78. In this Figure 78, the window of opportunity to design and develop mutually compatible artifact frames is shaped by the themes and related sub-themes of Table 11.

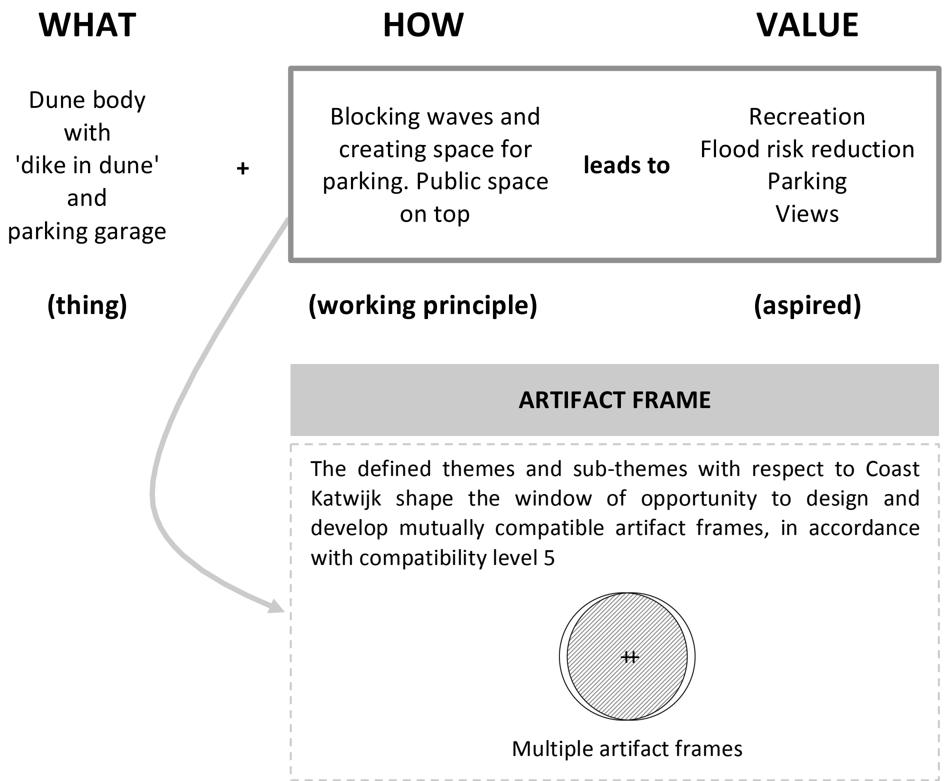


Figure 78 Scheme on headlines for system Coast Katwijk from a design perspective

In elaboration of the formulated themes and sub-themes can be said that the experience of conflict in former projects such as Noordwijk and Scheveningen, respectively with respect to parking facilities, gave the Municipality of Katwijk the opportunity to overthink their own case and their definition of the problem and/or opportunity space. In addition, the application of the 'dike in dune' created space for the opportunity to apply a parking garage from a structural point of view. However, it was also the space that was given by the Regional Water Authority of Rijnland by adjusting their policies. The Regional Water Authority of Rijnland already took into account a certain structural space. The further embedding in the larger 'Hoogwaterbeschermingsprogramma' as a defined frame created space for the broader development of project Coast Katwijk. Therefore, Table 11 presents the motivation for integration as driven by experiences of conflicts in former projects in combination with availabilities that were present or created to combine different functions. The relation of Coast Katwijk with the 'Hoogwaterbeschermingsprogramma' shows that the momentum of sequence with respect to other projects, and the momentum as 'part of larger program' formed essential conditions for the integrated design process. Flood risk reduction and derived improvement of the primary sea defense can be stated as the aspired value that is leading in case Coast Katwijk, which shapes the window of opportunity for other forms of aspired value. The application of a parking garage is lower in hierarchy and can therefore be placed in a cascading effect of functions and corresponding forms of aspired value, as schematically presented in Figure 79. The cascading effect means that opportunities follow from the initial idea or working principle of the corresponding leading form of aspired value.

The integration of the parking garage and the primary sea defense was differentiated on several levels of scale. Coast Katwijk shows that the parking garage and primary sea defense are modularly related on the scale of these independently defined systems. The institutional responsibilities and lifecycles shape this differentiation on the scale of the parking garage and the 'dike in dune'. However, the system shows a uniform structure in accordance with compatibility level 5 on the scale level of the dune, which is related to the perception of the system and the original motivation for integration. The motivation for integration was expressed with respect to the scale of the dune and the design aspect 'space'. The aspired integration is therewith context dependent, as presented in Table 11.

In addition, the 'new type of project' also incorporated uncertainties and many stakeholders during the process. The appointment of capable people that functioned in a strict organizational, but open structure, formed essential conditions as well. The open structure was shown by opportunities for all stakeholders to think along, which led to the North-South extension of the project scope. The availability of the construction equipment for the construction of the dike-in-dune and the parking garage increased the opportunity space for incorporating this form of aspired value.

The strict organizational structure also incorporated a structure for 'understanding each other's systems' to support the 'shared ambition' in the project team. After the design phase, the design was agreed on detail level to secure the quality of integration during construction and operation.

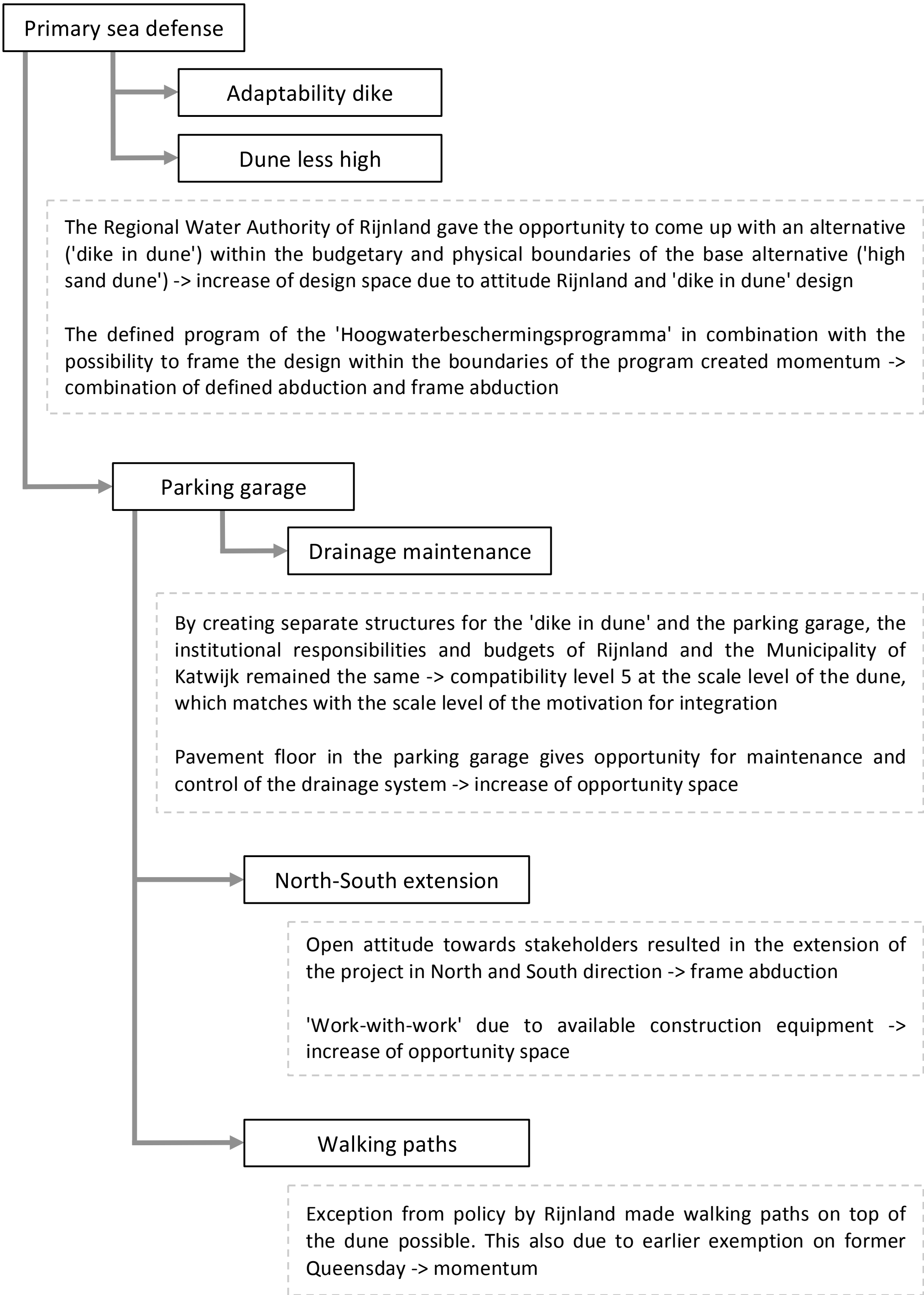


Figure 79 Cascading effect through integrated design for Coast Katwijk

6.3 Case: Benthemplein

6.3.1 Case Description and Analysis

Clients:	City of Rotterdam Rotterdam Climate Initiative Regional Water Authority Schieland en de Krimpenerwaard
Design:	De Urbanisten (landscape design)
Location:	Rotterdam
Project status:	Completed in 2013
Square size:	9.500 sqm (incl. street and parking) Effective square: 5.500 sqm Offering: 1.800 cbm temporal water storage
Cost:	4.5 million euro

a) Motivation for integration

About 15 to 20 years ago there was a large challenge with respect to the water buffering capacity of the City of Rotterdam. For this challenge, the regional water authorities and the sewerage manager came together to come up with a solution to increase the buffering capacity of the city. Some parts of the city contained green spaces, which could support water buffering, but other parts, such as the 'Oude Noorden', the old North part of the city, did not contain these spaces, as interviewee (2.1) explains. This observation led to the conclusion that the old neighborhoods in the city, that were built before World War II, did not provide enough space to come up with a traditional solution of single defined water buffering facilities. In addition, interviewee (2.1) explains that it is almost impossible to facilitate land for such mono-functional facilities as a municipality. interviewee (2.1) says about this:

> *'At the edges of the city this is possible, but in the city this almost impossible. We cannot facilitate space for a pond, while also a building of 25 stories can be built on that land. That has a different economic value. Our people at economics say: 'we are not going to facilitate land to dig for water'. So, when you want meet the challenges you both have, you have to reason in a different way and look how you can realize the integration of water in, under, on top, or close to. Without such a way of reasoning and approach, we do not make it'*

To structure solving these issues, the municipality developed the 'adaption strategy', as a starting point for the further development of a climate adaptive city.

In the process of looking to align climate adaptation and city development in the City of Rotterdam, the idea to apply a water square came up. The initial idea for a water square was already presented at the Architecture Biennial and 'Water Plan 2' of the municipality. Now, the municipality also started to look for possibilities to apply a water square in the City of Rotterdam.

About 10 to 15 squares were selected in different neighborhoods with challenge of buffering water and the need for an upgrade of the living environment. Some squares already got an upgrade recently, and others were facing opposition of local residents due to the inability to swim in case of accident. At last, 3 squares were selected and Benthemplein was designated as the square where the water square concept would be applied, as interviewee (2.1) explains. A condition in the selection of the squares was a minimum size of 1.500 square meters, because the City of Rotterdam, the Rotterdam Climate Initiative, and the Regional Water Authority Schieland en de Krimpenerwaard wanted to develop an iconic project. This was initiated because of the decreasing appreciation for the work of the regional water authority for example. Interviewee (2.2) tells about this:

> *'An OESO report presented that the regional water authorities are very useful and effective, but the weak point is they are very invisible. That is also a sort of anti-commercial. You are not visible and therefore unappreciated. From that point we changed to a more visible approach at the regional water authority. What kind of work we do, but also the usefulness and the effectiveness in parallel'*

The awareness of the importance of the different institutions was an important driver for this project. However, the importance of this work was especially emphasized in the context of climate change.

The increasing need for capacity to buffer water in combination with the lack of property in the city was the reason for the regional water authority to search for integrated solutions. Interviewee (2.2) says about this:

> *'It is always difficult in such a city that we have hardly any properties, which means a lack in means and tools to execute projects independently. So we have to do it in collaboration'*

The combination of the lack of space in the inner City of Rotterdam to increase the water buffering capacity, and the increasing need to show the importance of the work of the regional water authority in times of climate change, motivated the initiation of water square Benthemplein.

b) Design aspects in relation to integration

Square and basin

During the design process, the project team discussed the possibilities of applying one large square or multiple squares. This was driven by considerations of integrating different groups of people on one large square, or giving smaller groups their own place.

One large square has the risk that one group dominates the square, which makes it possibly less accessible for other groups, as interviewee (2.1) explains. However, separated squares can give a comfortable place for different groups of people, but impede integration of different groups. Going along the different considerations for the design of the square finally resulted in three basins that all have their own identity and are connected with each other. The basins are filled in another way, in which 2 basins have a direct inflow of water and the third and deeper basin fills when the sewerage system cannot cope with the rainwater runoff anymore. The third and deeper basin is 2.6 meters deep and is filled up in a later phase than the other 2 basins, as presented by Rietveld (2014). The collage of Figure 80 gives an impression of the different basins without water.

Figure 80 Impression of the three different basins of Benthemplein without water
Source: 1) Landscape Record (n.d.a); 2) De Urbanisten (n.d.a); 3) De Urbanisten (n.d.b); 4) Landscape Record (n.d.b)

In addition to the direct inflow of rainwater, the different basins are also connected to different surrounding buildings. The rainwater runoff system of these buildings was decoupled from the sewerage system en coupled to the basins. Figure 81 gives a scheme of the coupling between the basins and the surrounding catchment areas.

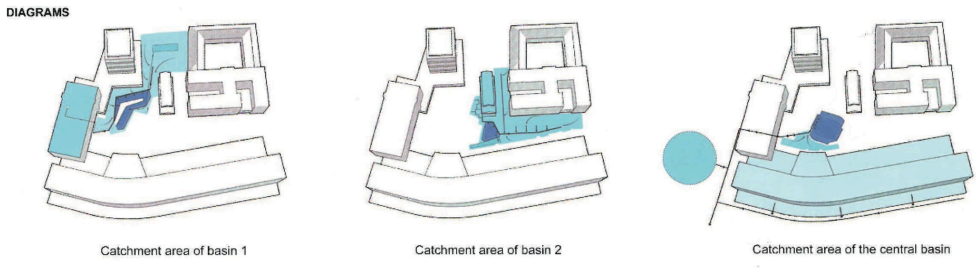


Figure 81 Scheme of the coupling between the basins and the surrounding catchment areas
Source: Landscape Record (n.d.c)

The three basins or squares of Benthemplein were designed below the norm of filling up once in 100 years. In practice, this would mean that the Benthemplein would fill with water every 100 years. This would also imply that there is a layer of 10 centimeters of water every 2 years. However, the water square was also intended to add to people's awareness about climate adaptation. For this purpose, therefore the norm for the basins was not set on 70 to 100 millimeter of water for design, but 35 to 50 millimeters buffering of water before the basins would fill up. In that case, the basins would fill up more often. This experimental norm could be realized within the city. In the case of for example a primary sea defense, coping with the general set norms would more sensitive. It was also possible to meet the norm and fill up the basins more frequently when half of the square size was connected to the rainwater runoff system, says interviewee (2.1).

Determining the size of the different basins, and the difference in filling speed, in relation to people's awareness was also mentioned by interviewee (2.2), namely:

> *'....you have to design the water square in such a way that it contains some water every year. Not that it remains empty for 10 years. Because, when it is raining hard in that case, everyone calls about the water on the water square....'*
>
> *'....Benthemplein has 3 basins, so some are designed in such a way that they also fill up with smaller amounts of rainfall. The big one is the tub that can take a lot of water. It also means that when it collects the water from the street, also trash comes with the water and you have to clean it after some time. And to keep the cost for maintenance and control within control, you do not want that it contains water every week'*

These notions of interviewee (2.2) also show the search for balancing the different interests, in this context between water buffering capacity, increasing awareness, and cost for maintenance and control. Figure 82 gives an impression of the, in terms of water buffering capacity, largest basin of Benthemplein when filling up or filled with water.

Figure 82 Impression of the largest basin of Benthemplein when filling up or filled with water
Source: 1) Landscape Record (n.d.d); 2) De Urbanisten (n.d.c); 3) De Urbanisten (n.d.d)

The maintenance, as already mentioned in the note of interviewee (2.2), is a point of attention with respect to the Benthemplein. For the larger trash, the municipality arranged with the Zadkine College that they would fulfill a role in the cleaning of the square of trash. The students and concierges would take care of this. Both for preventing that trash would come in the water when the basins are filled, as preventing the deeper squares to become trays of trash, which could be blown in by the wind. This arrangement was not fulfilled up to now, as interviewee (2.1) and interviewee (2.2) state.

However, the largest pollution issue is caused by sediment or dust on the basin floors. When the sediment is concentrated in certain corners by the wind, it is easier to clean than when the sediment is distributed over the basin floors. The inflow of water on particularly the large basin makes that the water distributes sediment over the floor. In addition, the floor material is not smooth enough, and the slope of the floor not steep enough, to runoff all the sediment. Therefore, the municipality has relatively high maintenance cost for cleaning the squares to guarantee a representative look of the squares, as interviewee (2.1) and interviewee (2.3) both note.

In sequential development of other water squares, or in redeveloping Benthemplein, the municipality is thinking of substituting the floor material for smoother material, and possibly increasing the slope of the square. In addition, the water from the surrounding buildings could be first buffered in a system in which the sediment can sink, before overflowing and distributing water over the square. In this way, the maintenance cost could be reduced as well, while the cleanness of the water on the square would improve, explains interviewee (2.1). However, the adaptability of the system is subordinate to seemingly severe intervention and large construction work. The square is 9.500 square meters in total, including street and parking. The effective square is 5.500 square meters and offers a capacity of 1.800 cubic meters temporal water storage (Landscape Record, 2016a). These numbers illustrate that when the square was only designed for the aspired value of public space, the City of Rotterdam should have incorporated temporal water storage of 1.800 cubic meters in another place in the city. From that perspective, the design of Benthemplein intensifies the functionality of the space, without compressing the space.

In the more extreme case that a project developer would like to develop a residential or office tower at the Benthemplein in the future, the municipality can in that case also demand the incorporation of 1.800 cubic meters of water buffering in the development plan, as stated by interviewee (2.1). In addition, interviewee (2.2) says about this way of 'strategic development':

> *'When for example 100 meters from here a new residential tower is being built, at that plot they have to incorporate a water buffering capacity of 70 millimeters of water. And the intention is to enforce this through a building decree of the municipality....'*
>
> *'....Most of them do not have this. This is extra'*

In this way, the incorporation of the water buffering capacity at Benthemplein creates opportunities for regenerative city development with intensification of the functionality of the space.

Square and public space

In addition to the water buffering function of Benthemplein, the square also has a social function. As already explained, the choice for three connected basins was made after extensive teamwork and discussion of the project team on group dynamics and the integration of different groups. The squares differ in addition to the time of filling also in spatial design for recreation.

The spatial design for Benthemplein was developed in close consultation with the surrounding stakeholders, such as stakeholders related to the school, the church, and the gym, and the residents of the neighborhood. In 3 sessions, each session 24 images were presented to structure this process and discuss the design and development of Benthemplein. The first set of images was about the desired atmosphere and presentation of the square, in terms of colors, materials, art, and soft or hard structures. The second set of images was about what people would like to do at that place, and how they would like to perceive it. This was for example about if and how people want to lay, sit, talk, and if they want to play football, or do urban sports such as skating. The third and last set of images was about which water elements people would like to see, such as flowing water, or some sort of fountains. Interviewee (2.1) tells that all the output from these three sessions with the different stakeholders was taken into account to integrate the water buffering system and the recreational system in the final design of Benthemplein. The slope of the water flowing system also facilitates possibilities for skating for example, as shown in Figure 83, which is the enlarged photograph number 2 of Figure 80.

Figure 83 The integration of water buffering and recreational facilities in one spatial design

Source: De Urbanisten (n.d.a)

In the design of Benthemplein, two main forms of aspired value were taken into account. The first main form of aspired value is flood risk reduction. This means that Benthemplein fulfills a role to reduce possible situations of flooding in the neighborhood in cases of extreme rainwater runoff. Benthemplein contains basins for water buffering to reduce the pressure on the local sewerage system. In addition, another form of aspired value is the quality of the public space. People should have the opportunity to lay, sit, sport, and meet each other in a space with a certain quality.

Looking at 'necessity' and 'availability', the water buffering function of the squares is only necessary in cases of extreme rainfall a couple of times a year. As already explained, the threshold for buffering water in of the large square of the Benthemplein is set on 35 to 50 millimeters of rainwater, which possibly happens a couple of times a year. Due to raising awareness of weather patterns and filling up the squares, the norm is set lower than the standard norms of 70 to 100 millimeters of rainwater buffering. With the lower threshold, the squares fill up more often, as interviewee (2.1) explains.

In contrast to the 'necessity', the 'availability' of the water buffering function should be continuous year round. The availability of the function of public space is less strict than the availability of the water buffering function. When the square is filled with water, the function of public space can be disturbed for certain sports. However, the function of the public space is desired, but not necessarily year round. Therefore, the combination of functions does not lead to severe conflicts in 'necessity' and 'availability' on the scale level of the square.

Square and surrounding facilities

The square is located between different buildings, related to different stakeholders. These stakeholders vary from, in the first place the residents of the Agniese neighborhood, to the Zadkine College, to Graphic Lyceum, the church, the Youth Theater and the David Lloyd gym (Landscape Record, 2016a). These different stakeholders have their own desires, which should be incorporated in the design. Because of the diversity of the surrounding stakeholders, these desires can be diverse as well. In the case that surrounding stakeholders, for example the David Lloyd gym, would decide to use the rainwater on the building for own purposes, the municipality can decide to connect other parts of the neighborhood to the square, as explained by interviewee (2.1). In that sense, the system that is related to the water buffering function is adaptable to changes in interests and water challenges in the neighborhood.

With respect to the 'accessibility', the church desired a floor level from the parking lots to the church without stairs. This to take into account that possibly not everyone is able to walk on unequal terrain, while everyone should be able to enter the church.

Incorporation of 'accessibility' was also required with respect to the emergency services. The emergency services demanded a minimal zone of 3 meters wide and 5 meters positioning space. Interviewee (2.1) says there is a wide stroke along the square that is flat for this reason.

The incorporation of the discussed topics with respect to 'accessibility' shaped the interfaces between basins and surrounding buildings and paving.

Spatial elements
Benthemplein contains several spatial elements on a smaller scale level than the three connected squares. From the three sessions with 24 images, the ideas of the stakeholders were translated into a design for the different squares.

Regarding color and atmosphere, the parts of the basin floors that would be covered by water in case of heavy rainfall were painted in blue, in motives that were derived from the work of the artist Karel Appel (Landscape Record, 2016a). The motives on the different basin floors can be observed in Figure 80.

In addition, the slopes and rails of the basins give the affordance to lay, sit, and skate. The largest square also contains a basketball net, goals, and field lines for playing different kind of sports on the large square. The smaller square gives more possibilities for skating, as already shown in Figure 83. The largest square also contains stairs that can be used as benches in case of performances on the large square.

The water elements, such as for example the filling system of the large basin, differ in time and way of filling from the other basins. This creates diversity and playfulness of the place. The gutters also contain a phased overflow system, dependent on the amount of rainwater runoff from the surrounding roof, as illustrated in the collage of Figure 84. These stainless steel gutters also serve as elements that increase the spatial quality of the artifact (Landscape Record, 2016a).

The spatial elements that are part of Benthemplein, such as the gutters, or the benches and stairs, are more open for adaptation than large concrete basins. These spatial elements can be adjusted with additional elements, in terms that people have for example more possibilities to sit, or small ramps for skating.

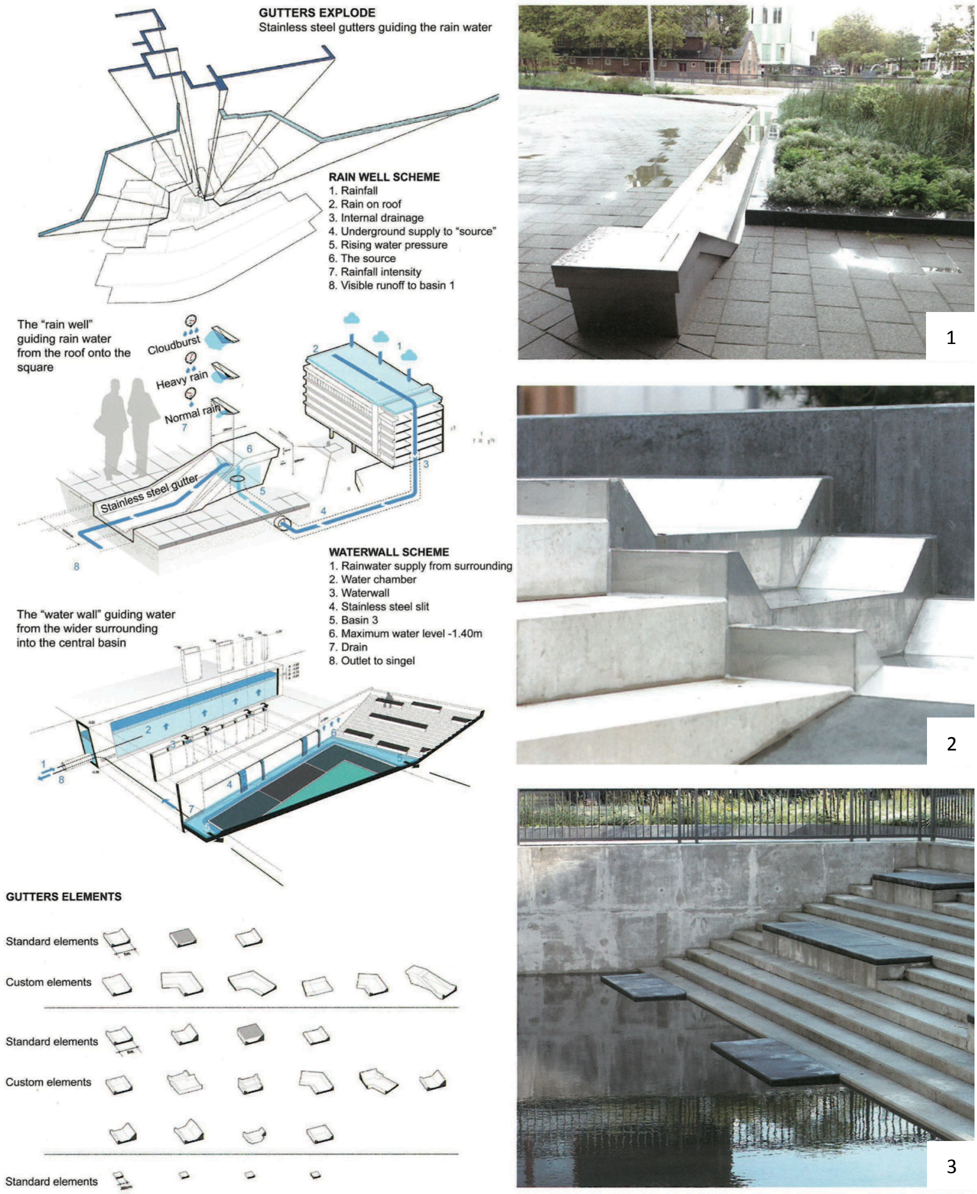


Figure 84 Impression of spatial elements that integrate the aspired value with respect to the water buffering system and the aspired value with respect to the recreational system
Source: 1) Landscape Record (n.d.e); 2) Landscape Record (n.d.f); 3) Landscape Record (n.d.g)

c) Conditions for the integrated design process

Sensitivity to environment

Interviewee (2.1) says that for the initial plan for a water square at another location in the city, the residents of that particular neighborhood became opponents of this plan due to lack of incorporation of their concerns and interests. In a sequential attempt to apply a water square at location Benthemplein, the environment was much more involved during the design process, which made the execution of the water square embedded in the neighborhood. Different surrounding stakeholders had different interests, which were all incorporated with care. The 'sensitivity to the environment' and involvement of stakeholders was an essential part in the development towards the current design. The 'selection of potential locations to apply' is related to the 'sensitivity to the environment' in this context. Interviewee (2.1) explains that before the redevelopment of Benthemplein, the square was not attractive. Interviewee (2.1) actually formulates it as:

> *'The good thing was that the square was so ugly that everything you would do was good....'*
>
> *'....So, when there is an upgrade of the square in front of your door and an investment of 3.5 million euros, there is not a lot of opposition. And the different stakeholders were also taken into account in the process in a good way'*

Therefore it was easier to obtain support from the environment for the redevelopment of Benthemplein. The 'selection of potential locations to apply' is an essential condition for stakeholder support and involvement in integrated design.

Part of larger program

Benthemplein is not a project that stands on itself, but is 'part of a larger program' of climate adaptation projects in the inner city. More water squares were applied in the city, but Benthemplein is probably the most iconic water square of these. Interviewee (2.1) explains that the concept of a water square already was introduced at the Architecture Biennale and 'Water Plan II' of the municipality at that time. Also the Regional Water Authority of Schieland en de Krimpenerwaard was looking for solutions to apply more visible solutions at the surface. The common interests of these different parties, in combination with the lack of property of the regional water authority and the lack of space for the municipality, led to a 'collaboration' in which especially the municipality was 'willing to pay' for an integrated solution. Additionally, the municipality also 'created room for design' during the design process. The momentum for these types of projects formed a condition for integration.

Extra budget

Interviewee (2.1) explains that the municipality invested 3.5 million euros in the development of Benthemplein to start the project directly. At least 1 million euros could be directed to the water buffering challenge and was funded by the regional water authority. In total, the project costs were covered by a European Union subsidy of 40 percent. Additionally, about 300.000 euros was funded by 'Mooi Nederland', and 100.000 euros by the councilor of the 'Youth Year'. Also the regional water authority invested a couple of tons of euros. This made that the project was covered for about 60 percent by subsidies or budgets from initiatives. These subsidies made a more expensive integrated design for Benthemplein possible. It shows that the total created value of Benthemplein can be higher due to integrated design, but that the project also should be eligible for 'extra budget', or as interviewee (2.3) proposes for 'combined budgets', in that case.

Ad hoc approach under evaluation
The development process regarding Benthemplein is mainly organized as 'learning on the way', because it is a 'new type of project' and 'testing ground' for innovative solutions to increase the water buffering capacity in the denser city parts of Rotterdam. This 'learning on the way' leads to the conclusion by Interviewee (2.3) that the project is 'falling in between departments' at the Municipality of Rotterdam at the moment. In addition, there is a 'discrepancy between ideation and operation'. This makes it complex in terms of relating to governance and budgets. At the moment, Benthemplein is marked as a special project. But, as interviewee (2.3) also explains, the 'ad hoc approach' of maintenance and control, and governance that is lagging behind innovative solutions such as Benthemplein, leads to more work. Also outside the municipality, the informal agreements, with for example the Zadkine College about keeping the square clean, seem not to be maintained, as stated by interviewee (2.1) and interviewee (2.2). The municipality feels responsible for keeping the square clean and therefore comes in action when necessary.

In the future, a clearer structure for maintenance and control would be desirable, but this will probably also has its impact on the structure of the organization within the Municipality of Rotterdam. Now, these types of projects still have to fit in a certain discipline and related budget. Interviewee (2.3) suggests that setting up an interdisciplinary management group with an overall budget for such types of projects could be supportive in managing these projects. Also formal legal responsibilities could support the management process.

6.3.2 Themes and Reflection

Section 6.3.1 explained case Benthemplein along the different topics 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. These topics came along in the interviews and were coded and categorized. In this section 6.3.2, the codes and categories are related to different themes and sub-themes per investigated topic.

Table 12 presents a summarized version of the different themes and sub-themes, without the related codes, categories, and interviewees. The complete table with the relation between interviewees, codes, categories, themes, and sub-themes can be found in Appendix C.2.

Table 12 Themes and sub-themes Benthemplein

Case: Benthemplein	
Topic: Motivation for integration	
Theme	Sub-theme
The combination of the lack of space and resources, and the desire to create a showcase form the main motivation for integration	Desire to create a showcase to increase awareness
	Mainly the lack of space and resources drives a need for integration
Topic: Design aspects in relation to integration	
Theme	Sub-theme
The aspired integration is context dependent	A visible and strategic addition of functions
	Hierarchy in functionality
	Different lifecycles determine integration choices
	Project responsibilities are defined in line with institutional responsibilities
Topic: Conditions for the integrated design process	
Theme	Sub-theme
Traditional internal organization and value frameworks form bottlenecks for development	Internal agreement can be a bottleneck
	Subsidies and extra funding required to obtain cost efficiency, and not every location is suitable to apply
Open, but strategically information in combination with assigning budgets to create commitment are key	Forced commitment can be obtained by assigning budgets
	Aligned mindset can be obtained when different ambitions come together
	Incorporate sensitivity to the environment to obtain collaborative participation by open communication, but informing strategically
Ad hoc approach causes many new challenges	Ad hoc approach due to new type of project
	The ad hoc approach results in confrontation with issues and learning points for sequential development

The system of Benthemplein is schematized on headlines from a design perspective in Figure 85. In this Figure 85, the window of opportunity to design and develop mutually compatible artifact frames is shaped by the themes and related sub-themes of Table 12.

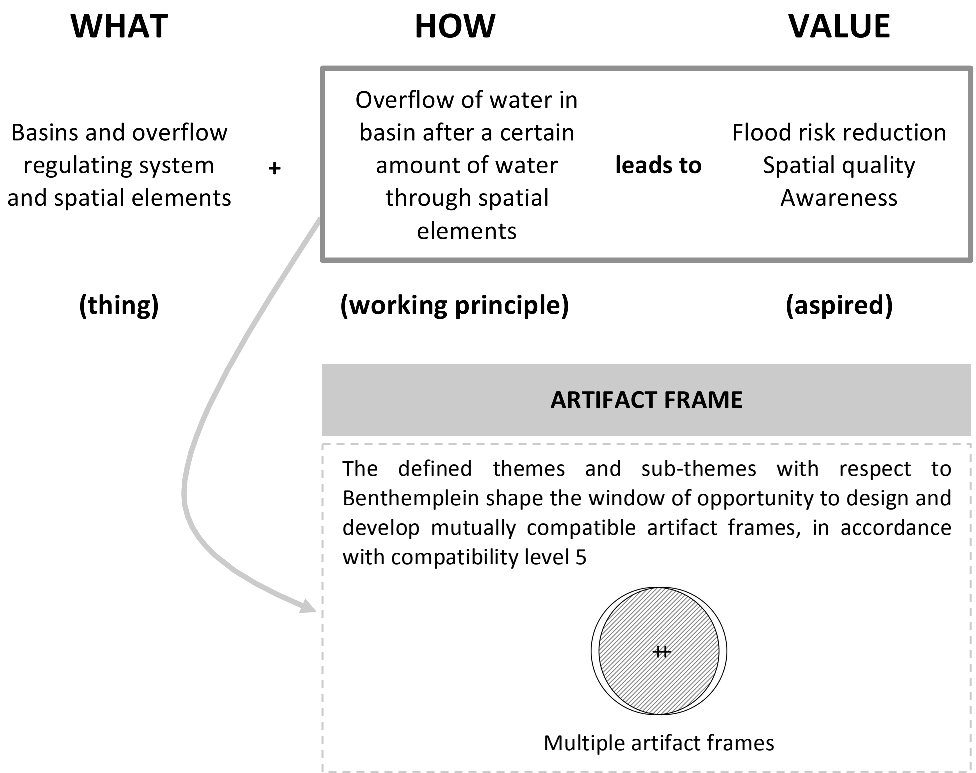


Figure 85 Scheme on headlines for system Benthemplein from a design perspective

The actual design of Benthemplein was initiated by the ambition of the Municipality of Rotterdam to apply a water square in the city at a location that also needed an update in terms of urban quality. The Regional Water Authority of Schieland and the Krimpenerwaard also had at the same time the responsibility to buffer water in the inner city parts. However, due to a lack of resources or land ownership within inner city boundaries, the regional water authority was actually forced to collaborate. They used integration to create certain facilities and fulfill their responsibilities. Table 12 shows that integrated design can be driven by the lack of properties, while the responsibility to create certain facilities remains. When the integration of functions becomes the norm at a particular place, integration is used as a means for strategic development.

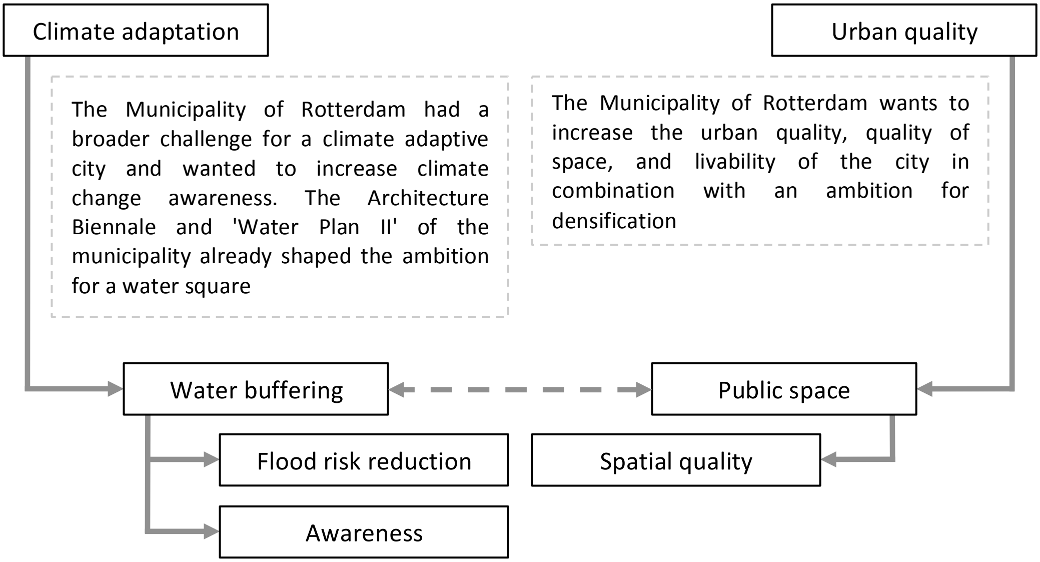
In addition to a means for strategic development, integration can also be used to increase the visibility of functions and responsibilities to raise awareness, as expressed in the themes and sub-themes of Table 12. The regional water authority was confronted with a perceived lack of urgency of their work in the public and political domain. Therefore, they tried to increase the visibility of their activities. This also shaped the requirements for the buffering capacity of Benthemplein. The basins should fill once in a while to raise awareness. The integration with the public space is particularly interesting, because people are in that case confronted with it.

Another theme that is presented in Table 12 is the application of strategic information. This was especially at stake with respect to the internal decision-making within the municipality. The lack of knowledge about the possible risks and uncertainties drove the municipality to adopt an ad hoc approach with respect to maintenance and control. The design space was ill-defined at the start of the project in relation to maintenance and control. Now, the municipality would like to have more structure for maintenance and control, and in future projects this structure would be defined on beforehand. Project Benthemplein can therewith also be seen as a testing ground for sequential water squares and integrated projects.

Project Benthemplein was driven by different ambitions of the municipality and a lack of resources of the regional water authority. The opportunity space that was created from these ambitions and forms of aspired value shaped the design space of Benthemplein and forms a cascading effect from two sides, which come together in the design of Benthemplein, as illustrated in Figure 86. It shows that momentum for integration is shaped by the window of opportunity of different ambitions and the need to integrate due to a lack of resources. The momentum for the regional water authority also embedded the opportunity to incorporate institutional responsibilities without land ownership, additional investments, or responsibility for maintenance and control. The regional water authority could use integration therefore also in a strategic way.

Focusing on the aspired integration, it can be stated that integration is context dependent. Case Benthemplein shows a clear hierarchy in functionality, which is reflected in a differentiation in types of functions. The differentiation shapes the aspired integration. The aspired value of water buffering and corresponding flood risk reduction go beyond the aspired value of public space in terms of critical functionality, so the water buffering function should always be available, while the public space can lack availability for a couple of days a year. This interplay of 'necessity' and 'availability' shapes the aspired integration. The largest basin with its designed filling control system for filling is the artifact element that creates the integration of the different forms of aspired value.

The active involvement of stakeholders during the design process showed a process of frame abduction in which the definition of the artifact frame is part of the design itself. At different scales, the design process was more or less defined to integrate artifact frames.



The Municipality of Rotterdam wanted to create a solution for water buffering due to hindrance of water overflow in the sewerage system in cases of heavy showers and increase climate change awareness. The Municipality of Rotterdam had also a challenge to update certain public spaces/squares in different city neighborhoods. They looked for opportunities to combine this update with the aspired water buffering -> increase of opportunity space and momentum

The Regional Water Authority of Schieland and the Krimpenerwaard was looking for opportunities to buffer water in the inner city parts and increase visibility, where they do not have properties or space that can be ruled by them for water buffering -> The Regional Water Authority of Schieland and the Krimpenerwaard and the Municipality of Rotterdam share similar forms of aspired value. Imposed constraints in combination with an aspired value for water buffering to reduce flood risk led to strategic integration

The water buffering and public space could be designed in one space. While not possible to obtain simultaneously, the different functions are not designed at the cost of each other due to the relation between necessity and availability. Both forms of aspired value are served through the design of the filling control system of the largest basin

Due to the aspired value of creating public space, the water elements at Benthemplein are designed with care -> 'Work-with-work' -> increase of opportunity space

The stakeholders were actively involved in the project in terms of desired atmosphere and elements that can serve them -> frame abduction

The new type of project asked for new types of structures for maintenance and control. These were not available at the time of the project initiation. Therefore, the choice was made for an ad hoc approach to create room for continuation -> ill-defined design space

Figure 86 Double-sided cascading effect through integrated design for Benthemplein

6.4 Case: Biomakery Strijp-S

6.4.1 Case Description and Analysis

Clients:	Regional Water Authority De Dommel Province of Brabant Municipality of Eindhoven Park Strijp Beheer
Design:	Biopolus/ West8
Location:	Strijp-S, Eindhoven
Project status:	In process of reconfirmation
Capacity:	1.600 cubic meters per day
Building surface:	222 square meters
Estimated cost:	5.5 million euro

a) Motivation for integration

Regional Water Authority De Dommel is confronted with an increase in fresh water consumption, while the ground water level is decreasing in some years due to longer periods of drought. In this context, Regional Water Authority De Dommel is looking for solutions to make more use of the fresh water reserves per unit of water. In addition, as interviewee (3.1) states, there is also a national ambition to be 100 percent circular in 2050.

After a documentary on the Dutch television about organic wastewater treatment, interviewee (3.2) visited the developers of this concept in Hungary. There they discussed the possibilities for applying such a facility for the Regional Water Authority De Dommel. Interviewee (3.2) tells about this process:

> *'I saw a documentary of Tegenlicht, 'Power of Water', and Organica Water came along. I have Hungarian roots and I thought I am going to visit that site when I am on a holiday in Budapest in the summer. And then I thought: we need one in The Netherlands. You have to imagine, you are standing in a jungle and the polluted water is flowing underneath you while cleaned at the same time. This is quite impressive. Then I put this concept on the innovation program of the regional water authority as a concept that could be interesting as a test ground project'*

Subsequently, Regional Water Authority De Dommel investigated the potential locations for such a facility and came up with a list of 60 locations. Then they reflected on these locations more stringently along the 12 criteria from the Water Management Plan, as explained by I. Koller (personal communication, November 1, 2019) of Regional Water Authority De Dommel. The criteria from the Water Management Plan are (I. Koller, personal communication, November 1, 2019):

1) Clear formulation of the question and the question is generalizable
2) The direction for solution is social/ circular economy

3) Users (industry and residents) have a role in the project
4) Art, culture, and media have a role in the project
5) Research and education are involved
6) Boundary condition: one or more entrepreneurs are involved
7) The project is profitable
8) Demonstrable contribution to water quality, availability, or safety
9) Demonstrable energy reduction or energy generation
10) Demonstrable reduction of resources or increase in Cradle to Cradle
11) Demonstrable new turnover and employment in the region
12) 20 percent higher attendance at the next regional water authority elections

Reflecting on these 12 criteria, 5 locations were selected in the end. These locations would be developed consecutively. The Abbey of Koningshoeven was developed first, representing an application near an Abbey. Thereafter, Strijp-S is a second application of the concept, but now in a neighborhood. In total, the 5 locations range from an Abbey to the neighborhood of Strijp-S, with residents and small-scale creative entrepreneurs, the High Tech Campus of Eindhoven, and heavy industry such as the Nyrstar sink industry. Together, they should represent a show lane of applications of circular water chains through organic treatment. Interviewee (3.4) says about this:

> *'We are not going to make traditional wastewater treatment facilities. That is purely functional, what it should do. We actually had the technology and we had to find a place to prove it. So, that is not first making a policy, then a plan, and then tendering it. No, having a certain technology, and finding a place for that. That is innovating the other way around. Innovation from your own strengths or competences, or from the technologies you have. Instead of setting market requirements and then bring it to a tender procedure. It is just the other way around. It is not 'outside-in', but 'inside-out', from your strengths'*

In this way, Regional Water Authority De Dommel also wants to increase the visibility of the work of the regional water authority and the awareness of people about water management facilities. In the context of this research, the focus is on the possible application at Strijp-S, because in the case of Strijp-S the integration of this concept in the public space is at stake.

The initiation of a so-called Biomakery at Strijp-S started in 2015. The motivation for this project was that a circular water chain in the neighborhood of Strijp-S would give the ability to keep the fresh water longer in the local water system. Interviewee (3.1) and interviewee (3.2) state that the capacity of the current water treatment system and sewerage network is sufficient and the project is not initiated because of a lack of capacity to discharge rainwater.

Traditionally, the treated water would have been discharged on the river and flow to the sea. However, the Biomakery will bring back the treated water in the local water system, not as drinking water, but for purposes as for example public water bodies. The application of the Biomakery at Strijp-S is therefore reducing the runoff of water from the local area, and the larger scale water system can become more resilient to periods of drought. This is particularly interesting for this area in comparison to other parts in the Netherlands, because it is located at high sand grounds. Therefore, the confrontation with reduced ground water levels in times of drought is harder, as interviewees (3.2), (3.3), and (3.4) explain. Interviewee (3.3) says about this:

> *'We have sand grounds in the East and South-East of the Netherlands, which have the disadvantage over the peat and clay grounds that they dry out. So, our ground water level decreased due to the two hot summers'*

Park Strijp Beheer is the owner of the development area of Strijp-S, and is a collaboration between the Municipality of Eindhoven and VolkerWessels. Park Strijp Beheer is interested in the application of the Biomakery, because it can give opportunities to apply attractive water bodies, and therewith a more attractive neighborhood. Interviewee (3.3) notes that another incentive is that the innovative Biomakery can also attract creative industries that want to cooperate and add to the development of the circular water system. This will also raise the attractiveness of Strijp-S.

The Municipality of Eindhoven is especially interested to solve their issue of water supply in the dry summer months. Interviewee (3.5) says that especially the permission of the province to pump up water during two dry months a year is crucial with respect to an agreement about this project. The Municipality of Eindhoven wants to use the Biomakery to infiltrate water 10 months a year, and pumping up water 2 months a year, which will result in a net positive balance in the amount of water that is infiltrated in the underground. In addition, the municipality is also interested to solve the issue of the polluted underground. The province is mainly involved on the base of goodwill to stimulate creative development towards a more livable and sustainable future. The 'interference of systems' is an important factor in constructing the motivation for integration. However, the different ambitions make the process of integration complex.

b) Design aspects in relation to integration

Biomakery building and spatial quality of the neighborhood

The Biomakery of Strijp-S is still in the development phase at the moment. Initially, there was an idea to integrate the technical facilities for the Biomakery in the parking garage at the time the parking garage was still under construction. However, Regional Water Authority De Dommel had to make a decision about the realization of Biomakery in that case within a period of three months time, which did not happen, as interviewee (3.1) explains. Therefore, the Biomakery is now planned as a separate facility in the neighborhood. The initial impressions that were made at the start of the design and development process on how the Biomakery could look like are presented in Figure 87. However, although these impressions show how the Biomakery could look in the neighborhood of Strijp-S, the actual design will have a different and less expensive type of architecture.

Figure 87 Impression of the initial design of the Biomakery at Strijp-S at day and night
Source: Tectobio (n.d.)

Although the initial design for the Biomakery, which is presented in Figure 87, seemed to be too expensive, the intention is still to realize the Biomakery in an architectonically integrated way. This means that it should be integrated in the architectural atmosphere and adds to the spatial quality of the neighborhood.

When the Biomakery is able to hold the local fresh water in the neighborhood of Strijp-S for longer periods of time, the amount of water in the area will be higher. This water can be used for a water body in the neighborhood, which will also increase the quality of the views and living area for the residents. In fact, more value per unit of water is created locally, which will increase the livability of the neighborhood. The water from the Biomakery and the public local water body are therefore integrated as part of a water management plan on the level of the neighborhood. The public water body and surrounding vegetation can also add to the mitigation of urban heat effects and loss of biodiversity, as stated by interviewee (3.2). Figure 88 gives an impression of a successive design for the Biomakery in relation to the public water body at night. However, the realization of the Biomakery in this form turned out to be too expensive as well, says interviewee (3.2). Nevertheless, Figure 87 and Figure 88 give an idea of the possible integration of the Biomakery in relation to a public water body and adjacent residential building.

Regardless what the possible final design for the Biomakery will look like, interviewee (3.2) and interviewee (3.4) state that the wastewater treatment system takes a factor 4 to 5 less space than a traditional solution for the same amount of treated water. Although the wastewater would not have been treated in the neighborhood as the Biomakery does, it provides on a larger scale also an interesting alternative in terms of used space. In addition, the orientation of the operational activities in relation to the Biomakery is also incorporated in the design. For example, the facilities with chemicals that need to be removed periodically are positioned at the railway trackside of the Biomakery. In this way, the trucks that transport the chemicals are out of the sight of the people and do not have to cross the neighborhood, as interviewee (3.2) explains.

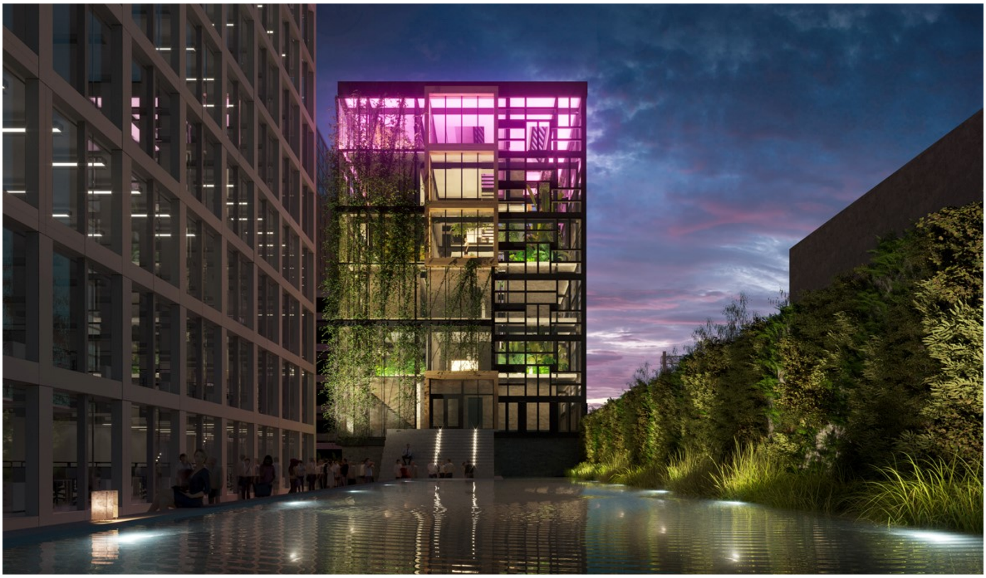


Figure 88 Impression of a preliminary design of the Biomakery to illustrate the relation between Biomakery, public water body, and residential building
Source: I. Koller (personal communication, November 19, 2019)

The spatial quality of the neighborhood will also increase by the possible creative industries and corresponding activities in relation to the Biomakery. This will make the neighborhood more attractive for additional investments and an increase in living quality.

The bad odors that are related with traditional wastewater treatment solutions are not part of the Biomakery. The type of treatment process facilitates a circular water chain without additional bad odors.

At the moment, the Biomakery is not open for the public. This has to do with the complexity of the application of the filtration facility, as well as its current budget. Interviewee (3.2) explains that in a next development phase, ideas to open it for the public can incorporated. The external space around the Biomakery can be integrated in the public space such as a small park.

Greening, remediation, and waste water treatment
The Biomakery contains Metabolic Network Reactors (MNR's) with more than 3.000 species of microorganisms. The roots of the plants in the reactor reach the wastewater and form together with the artificial roots in between a dense and compressed system. The microorganisms on the roots clean the water, and because of the metabolic interchange between plants and microorganisms, the system becomes more robust (Biopolus, n.d.). Figure 89 illustrates the plant based clean process that is part of the Biomakery facility.

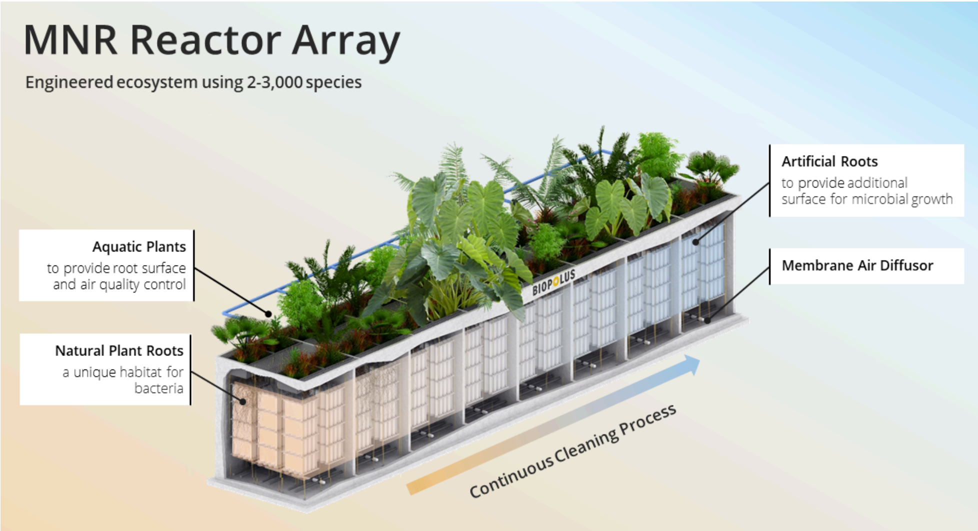


Figure 89 Illustration of the MNR Reactor Array
Source: Biopolus (n.d.)

The integration of plants and wastewater treatment results in opportunities to integrate the Biomakery in an urban area and make this area greener. The wastewater treatment process does not come with hindrance of odor and uses less space (I. Koller, personal communication, October 3, 2019). An additional benefit of the Biomakery is that it is able to remove higher concentrations of for example medicines from the water in comparison to traditional solutions, as interviewee (3.4) explains. This can be useful when norms can become higher in the future.

Another benefit is the possibility to clean ground water locally, which is particularly of interest for Strijp-S. Due to former Philips industries ground water bodies are polluted and need to be cleaned. However, interviewee (3.3) notes that although Philips maintains its responsibility to monitor the pollution in the underground, the reorganization of Philips influenced the prioritization of indeed cleaning the underground in a bad way. In this context, the Biomakery can potentially also form a treatment facility for the polluted ground water. However, if the polluted ground water can be transported to, and cleaned by the Biomakery is not tested yet (I. Koller, personal communication, October 3, 2019). The cleaning of the pollution in the underground was initially not defined as a main function or motivation for integration. The function seemed to be less dominant in the functional hierarchy. However, the possible cleaning of the underground seems to become increasingly important. Especially for the Municipality of Eindhoven, the cleaning of the polluted underground would mean they could solve this problem and their duty to care for this problem over time. It also creates opportunities to use the maintenance budget for other purposes. Interviewee (3.5) notes about this aspect:

> *'There is also ground water and underground pollution in that area. When I can connect one of the streets in the Biomakery to the ground water, and I can clean the ground water, then this is highly valuable for me. Now, it is a large stain that is as the sword of Damocles above our head. When I can clean the water, and maybe it has to go 10 times through the Biomakery before it is clean enough, but now it is there for eternity. An eternal during duty to care. When that stain is gone in 10 years time, then I am also unlocking money, so I can give the regional water authority a yearly budget what supports them to pay for the costs of that cleaning process'*

The initially less dominant function of the cleaning of the underground can then possibly even become essential in obtaining a feasible business case over time.

Off-grid wastewater treatment and urban water management

Because the Biomakery represents a concept of local wastewater treatment, the clean water can also be used in the neighborhood itself. This was already described for the water body in front of the residential buildings. The Biomakery will not use rainwater, because it is not necessary to clean this water, but it can discharge water on the Grote Beek to use the water from there for irrigation of the local green, and increasing the level of the local water bodies in times of drought. In addition, it can reduce the pressure on the current sewerage network (I. Koller, personal communication, October 3, 2019).

The fresh water supply for residents should be available at all times. However, there is a difference in the amount of used water during the day and for different times of the year. The necessity is therefore dynamic with the differences in demand. This will also cause differences in the amount of wastewater that will be discharged from the houses during the day and for different times of the year. There are already residents at Strijp-S, which are now connected to the central sewerage network. Therewith, the residents already have the necessary facilities for their use and discharge of water at the moment. Although the residents will not perceive a difference in their way of using the water system, the Biomakery will be the visible object that marks the change in the treatment of waste water. Interviewee (3.2) states that because of the already operating traditional system, the Biomakery can start up slowly and the water management system has the ability to turn back to the traditional facility in the case of issues.

The public space of the water body that is connected to the Biomakery is not critical in terms of functionality, and neither has to be available at all times. Investigation should be executed which conditions are necessary for which flora and fauna. Additionally, the preferable availability of the benefits of the public water body for mitigating urban heat effects should be investigated in relation to water management plans.

For the involved parties that want to test innovative techniques in relation to the Biomakery holds that external operations can disturb local residents. They have to take into account that they act in a neighborhood with corresponding requirements for operation. Therefore, it can be the case that for example at night the facilities are not open for maintenance and control.

The responsibility for the maintenance of the Biomakery is not defined yet. However, the intention of the regional water authority is to split the maintenance and control in ordinary maintenance and control, maintenance and control with respect to innovation, and maintenance and control with respect to the infrastructure that is necessary when the water leaves the Biomakery. The Municipality of Eindhoven and Park Strijp Beheer will be responsible for maintenance and control with respect to the infrastructure that is necessary when the water leaves the Biomakery. The regional water authority is not automatically responsible for the infrastructure regarding for example transporting water through a neighborhood. This has to be discussed and agreed with the specific municipalities, also with respect to the possible financial contribution of the regional water authority.

The ordinary maintenance and control of the Biomakery will be left to the contractor or becomes part of a procurement procedure. The regional water authority has a certain structure of working with respect to wastewater treatment facilities. The innovative concept of the Biomakery would mean that the internal structure of the regional water authority also has to change with this new concept. However, the regional water authority does not prefer this, and ordinary maintenance and control is therefore left to the private market. At last, the maintenance and control with respect to innovation will become the responsibility of the regional water authority. Interviewee (3.2) states that at Regional Water Authority De Dommel there is a small group of people that can act quickly when it comes to maintenance and control with respect to innovation.

c) *Conditions for the integrated design process*

Cost efficiency and procurement rules

The budget of the filtration facility is limited on 5.5 million euros, which makes that the procurement can be done without the obligation to make it subordinate to European procurement rules. European procurement rules would make the process towards application much more complex and time consuming, taking away the interest of the involved parties and the momentum for application of innovation.

Interviewee (3.2) says about the European procurement process in relation to the process of the Biomakery:

> *'The extended initial design was too expensive. It was about 7.5 million euros and we have a budget that is limited by the European procurement rules, which is 5.5 million euros. That is not without a reason. We definitely do not want to get into a procedure of European procurement. That takes such a lot of time, and then the innovative momentum is gone. Then it becomes too complicated'*

The budget for Regional Water Authority De Dommel was additionally also based on parameters of wastewater treatment in traditional solutions. Interviewee (3.2) explains that for traditional solutions Regional Water Authority De Dommel calculates with a budget of about 500 euros per unit of pollution. The planned facility should function for about 10.000 units of pollution, which makes that the calculated budget in a traditional approach would also be about 5 million euros (I. Koller, personal communication, October 3, 2019).

At the start of the project Regional Water Authority De Dommel and VolkerWessels agreed on a public-private collaboration in which both parties would take 50 percent of the costs. However, over the years this shifted to a public-public collaboration with the Province of Noord-Brabant, the Municipality of Eindhoven, and Regional Water Authority De Dommel, because the project became more categorized as a long-term innovation project than a short-term realization of a wastewater facility. Before the governmental elections, the Province of Noord-Brabant, the Municipality of Eindhoven, and Regional Water Authority De Dommel agreed on a distribution of costs for the Biomakery, in which each of these three parties would take one third. However, the elections for the province and the regional water authority resulted in a new setting of people and parties in the government with their own plans and ideas. This also resulted in the statement that the agreement about the continuation and the distribution of the costs has to be reconfirmed. Interviewee (3.2) says that the different involved parties are now working towards a reconfirmation of the initial agreement. It illustrates that the 'political lifetime' can be a bottleneck as well.

However, the realization of the Biomakery will also change the relation between local water management and the neighborhood. The Biomakery will represent the decentralized facility that forms a central role in the water management and water related activities and innovation in the neighborhood. The centralized network will form the base facility, added with decentralized capacity. In this way, local water needs and discharges can be managed locally and the investment and maintenance cost of large-scale centralized networks can be reduced (I. Koller, personal communication, October 3, 2019). However, this asks some creativity in finding a positive business case. As interviewee (3.4) states in this context:

> *'....For sustainability you always have to look for different cash flows'*

The different defined functions give in this context opportunities for 'coupling to budgets' to obtain a positive business case.

Momentum
Funding and momentum are strongly related to each other. The 'cost efficiency' of the project is essential to obtain a feasible project. However, even when the project is cost efficient, the different parties can have a lack of budget when it is needed.

Interviewees (3.1), (3.2), and (3.5) also note in the context of the cost efficiency of the project that the integration of the technical facilities in the parking garage would have saved about 2 million euros, because the facilities for construction were already in place and the Biomakery did not need a completely separated building. In that case, the project would already have been realized at this time. However, as described, the regional water authority had to make a decision within a period of 3 months time to benefit from the already available and operating construction equipment and construction of the parking building. The regional water authority did not make a decision within that period of 3 months time. Therefore the Biomakery is now planned as a separate building.

The point of momentum seems to be crucial in integrated projects such as the Biomakery, there all interviewees (3.1), (3.2), (3.3), (3.4), and (3.5) refer to it, as can be observed in Appendix C.3. The momentum in the decision-making process is a crucial, but also a sensitive aspect. Especially in a project that is 'part of a larger program', as is the Biomakery. Interviewee (3.5) says about this:

> *'When I am going to develop a new terrain, for example the Brainport Industry Campus, BIC, when we apply a Biomakery there, I am not going to construct a sewerage network as an alternative, or as a back up so to say....'*
>
> *'...Therefore I wanted to start with the Biomakery as soon as possible, as a pilot, to test how clean the water will become. Can I use it? It takes more and more time. That has all kinds of reasons, but if you are still in time for BIC....? In BIC, I am a little bit nervous, because when I am going to apply it there, and it does not work, then the complex is built, and then I have to do it, something sub-optimal, with the spaces that are still left....'*
>
> *'....Then I do not have a back up anymore. Then, it is easier to go with the building process to construct a decent and robust system. That the parties that are going to get a company or house over there have a robust sewerage system. That is also a time element, which I am confronted with continuously. However, the city is always running. So for me it is not the reason, even when it can be applied in only a year, to say no to Strijp-S and the Biomakery. On average, every 30 years, an area is going to be redeveloped in the Netherlands. So, when it is not BIC, it is another place where I can apply it. It is a pity that I miss a development like this now, a missed opportunity so to say'*

To reduce issues with respect to the momentum of decision-making, interviewee (3.4) explains that they tried to take away these possible issues by an acceleration team:

> *'When I hear doubts, I do not call this opposition, because they are in general quite motivated for such cases, they like it, so I do not call it opposition, but there are doubts, question marks, and uncertainties of letting loose. Then I accelerate instead of slowing down. And through acceleration you can show things that convince them'*
>
> *'For example, we did not have to use it at Strijp-S that much; the steer group was called acceleration team by us. We started with this at La Trappe. The Commissioner of the Queen, the Prior, the 'Dijkgraaf', and the Councilor were part of the acceleration team. On itself this is a very nice formula, because it means that you leave the work and the application to the people in the field, who have to do it, which was our team. We got a lot of support, but only when we were confronted with something, then we got back to the acceleration team with the question: we are confronted with this, can you use your connections or can you do this or that? It is again the reverse way of a steer group'*

However, this also implies some new roles in governance, as interviewee (3.4) explains:

> *'And governors have really difficulties with being an accelerator. Then they do not have to decide on anymore. That is strange, a meeting where you do not have to decide on. That is strange. Then suddenly you have to serve. Then you have to look how you can help them. That is a different role'*

The adaptation to new roles in governance can therefore also be added to the 'lagging process of governance'. This 'lagging process of governance' is also caused by the different 'independent responsibilities' and corresponding interests of the stakeholders. This becomes even more at stake in such a 'new type of project'. As interviewee (3.5) illustrates when he describes the situation for the Biomakery at Strijp-S:

> *'The province thinks it is a very interesting idea, but you are confronted with all kinds of laws and regulations. When there is a draining prohibition, then this is the case. Then the lawyer of the province does not say: the Municipality of Eindhoven gets an exemption. And how does it work when I infiltrate water in the underground at one place, because that was the most beneficial location for nature and agriculture, but I want to take it out of the underground at 6 or 7 different places. Otherwise it takes all kinds of transport movements, which is not good for the level of CO2, not good in terms of sustainability. So, I want to take it out of the underground at another place than where I bring it in. That comes with all kinds of juridical things'*
>
> *'....But for the province it also means they have to adjust policies. The province is also organized in different columns within the province. So, that is a difficult one. I*

do not believe there is a governance problem at the province, but with the execution of the case, they are confronted with the fact they have to adjust their policies. And you are constantly confronted with things you do not think of on beforehand'

Interviewee (3.5) illustrates that finding the balance between momentum in decision-making and the ability to use this momentum despite a 'lagging process of governance' due to different responsibilities and interests in the context of such a 'new type of project' remains a challenge.

Level of ambition and open system development

With the plug-and-play set up, the opportunities for innovative development over time are integrated by the way the Biomakery is designed. The plug-and-play set up of the Biomakery makes the facility open for parties, such as knowledge institutes and entrepreneurs, which want to test new techniques. The set up of the facility makes it possible for testing innovative solutions under the condition that for the residents the quality of the water facility is still guaranteed, as interviewee (3.2) explains. Although there should always be a guaranteed delivery of water with a quality that is meeting the stated norms, the implications of the application of the Biomakery cannot become completely defined on beforehand. Interviewees (3.1), (3.4), and (3.5) therefore emphasize the importance of a 'testing ground' to open up 'scalability' of the technology. This testing ground also implies that not every aspect of the new technology can be thought out on beforehand. A certain 'level of ambition' is therefore essential according to all interviewees (3.1), (3.2), (3.3), (3.4), and (3.5), see Appendix C.3. Interviewee (3.3) and interviewee (3.4) add in relation to the level of ambition that respectively 'courage' and 'letting loose control', are important conditions in the integrated design process as well. 'Letting loose control', as interviewee (3.4) explains, can be interpreted as leaving the direction of development to a large extent to other capable parties.

The intention of Regional Water Authority De Dommel is to continue the development of the Biomakery after completion of the construction. New parties should be able to test innovations in relation to circular water chains with an easy plug-and-play system. There are also ideas to for example apply a restaurant or coffee bar on top of the Biomakery, and to open the 'botanical garden' for the public. However, interviewee (3.2) states that these ideas are still marked as possible further developments at the moment. Nevertheless, the possible development of these ideas in later phases should be incorporated in the current design.

6.4.2 Themes and Reflection

Section 6.4.1 explained case Biomakery Strijp-S along the different topics 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. These topics came along in the interviews and were coded and categorized. In this section 6.4.2, the codes and categories are related to different themes and sub-themes per investigated topic. Table 13 presents a summarized version of the different themes and sub-themes, without the related codes, categories, and interviewees. The complete table with the relation between interviewees, codes, categories, themes, and sub-themes can be found in Appendix C.3.

Table 13 Themes and sub-themes Biomakery Strijp-S

Case: Biomakery Strijp-S	
Topic: Motivation for integration	
Theme	Sub-theme
The motivation for integration is driven by the combination of linking to other cases and the need to solve the degenerative interrelation of systems	Opportunities to link to other cases and anticipate future policies
	Different systems have a degenerative interrelation
Topic: Design aspects in relation to integration	
Theme	Sub-theme
The aspired integration is context dependent	Project becomes strategically when part of a broader ambition
	Dominant functions drive feasibility
	Political lifetime can be a bottleneck
	Project responsibilities are defined in line with institutional responsibilities
Topic: Conditions for the integrated design process	
Theme	Sub-theme
Momentum in decision-making is key	Agreement is subordinate to political lifetime
	The momentum in decision-making as part of larger program or coupling to other programs can be a bottleneck
Momentum in stakeholder ambitions and involvement do not match with process of governance	The individual ambition of people, and the willingness to do and dare something innovative is key
	Agreement to use momentum is lagging behind when there is not a shared ambition
	Capable people and organizational capacity are key in this new type of project
	Actively involving stakeholders in an open, but strategically way is key
	The lagging process of governance can be a bottleneck

The system of Biomakery Strijp-S is schematized on headlines from a design perspective in Figure 90. In this Figure 90, the window of opportunity to design and develop mutually compatible artifact frames is shaped by the themes and related sub-themes of Table 13.

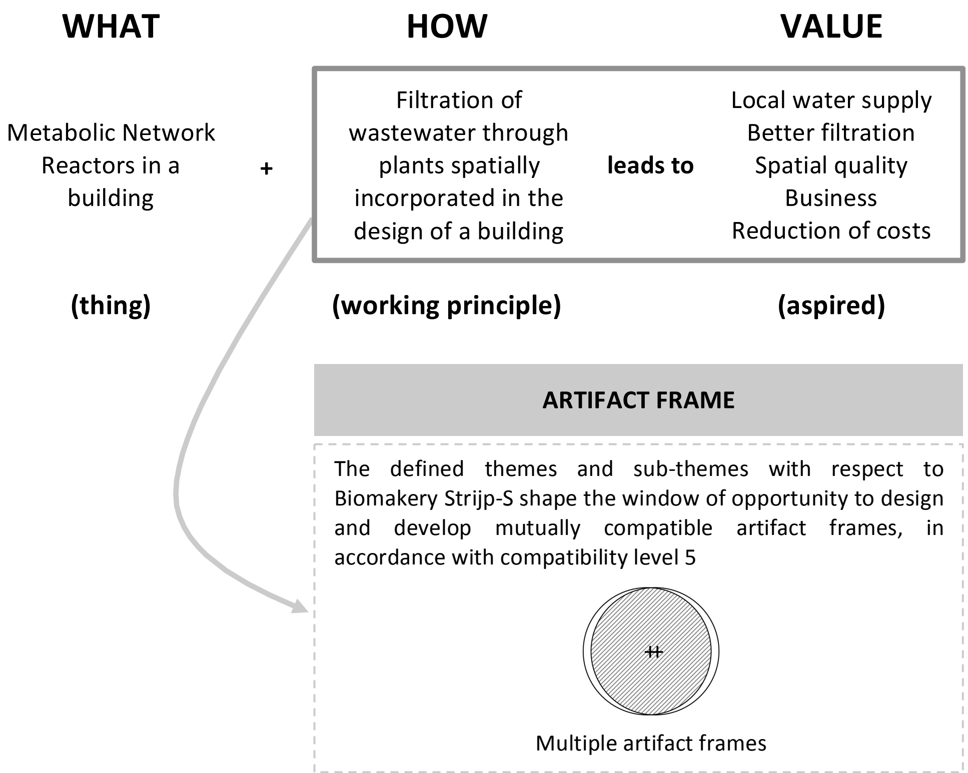


Figure 90 Scheme on headlines for system Biomakery Strijp-S from a design perspective

Reflecting on the themes can be said that the first theme shows that the motivation of integration is driven by both opportunities and conflicts. Especially the linking with other cases at the particular building site creates opportunities with respect to available construction equipment and room for construction. The opportunity to integrate the structure of the Biomakery with a parking garage at Strijp-S had passed due to the fact that the decision-making with respect to the Biomakery could not be completed within three months. This did not match with the pace of the construction process of the parking garage. However, although the window of opportunity for integration with the parking garage was not utilized, the degenerative interrelation between different systems, such as the increasing need for water in combination with increasing periods of drought in summer, has to be solved says interviewee (3.4).

In addition, the themes and sub-themes in Table 13 also show that the aspired integration is context dependent. The motivation for integration already showed that Biomakery Strijp-S is part of a so-called 'showlane' of projects. This forces decision-making parties on the one hand to keep the process going on for the particular case of the Biomakery Strijp-S. However, when the results of one project are used for the start of another project, it can also cause a chain of delay, and then the political lifetime can become a bottleneck. The integration of the project in a 'showlane' of projects can in that situation slowing down the process and decrease the window of opportunity and the opportunity space.

When it comes to the conditions for the integrated design process, the momentum in decision-making is crucial, but the integrated interests and aspects make it a complex interrelated setting. In addition, governance structures are lagging behind to keep up with the momentum in decision-making. However, there are many stakeholders, budgets, and governing processes that have to come together. It also implies that the process slows down when one of these is not available at a particular moment of decision-making. The complex setting of case Biomakery Strijp-S made that the principals now scaled the project down to its basic functions to reduce complexity. However, the reality shows that the interplay of different functions is crucial with respect to different stakeholder ambitions and for obtaining a possible positive business case. The changing hierarchy of functions, and related institutional responsibilities, in the case of Biomakery Strijp-S, illustrates an example of the interrelated setting. The project was initiated by the Regional Water Authority De Dommel to anticipate on the future circular water ambition and increasing filtration requirements. From this idea different additional opportunities cascading from the possible application of the Biomakery, as schematized in Figure 91.

However, the regional water authority does not have the position, power, and urgency to apply and invest solely. While the regional water authority is discussing the options with the other stakeholders, the Municipality of Eindhoven seems to become more in the lead of the project. Their interests in extracting ground water and cleaning the underground seem to become more urgent over time. However, the municipality is depending on the approval of the province to extract water from the underground in dry months. The province is not very enthusiast about the necessity to adjust the general policy and this defined and imposed constraint delays the decision-making of the municipality.

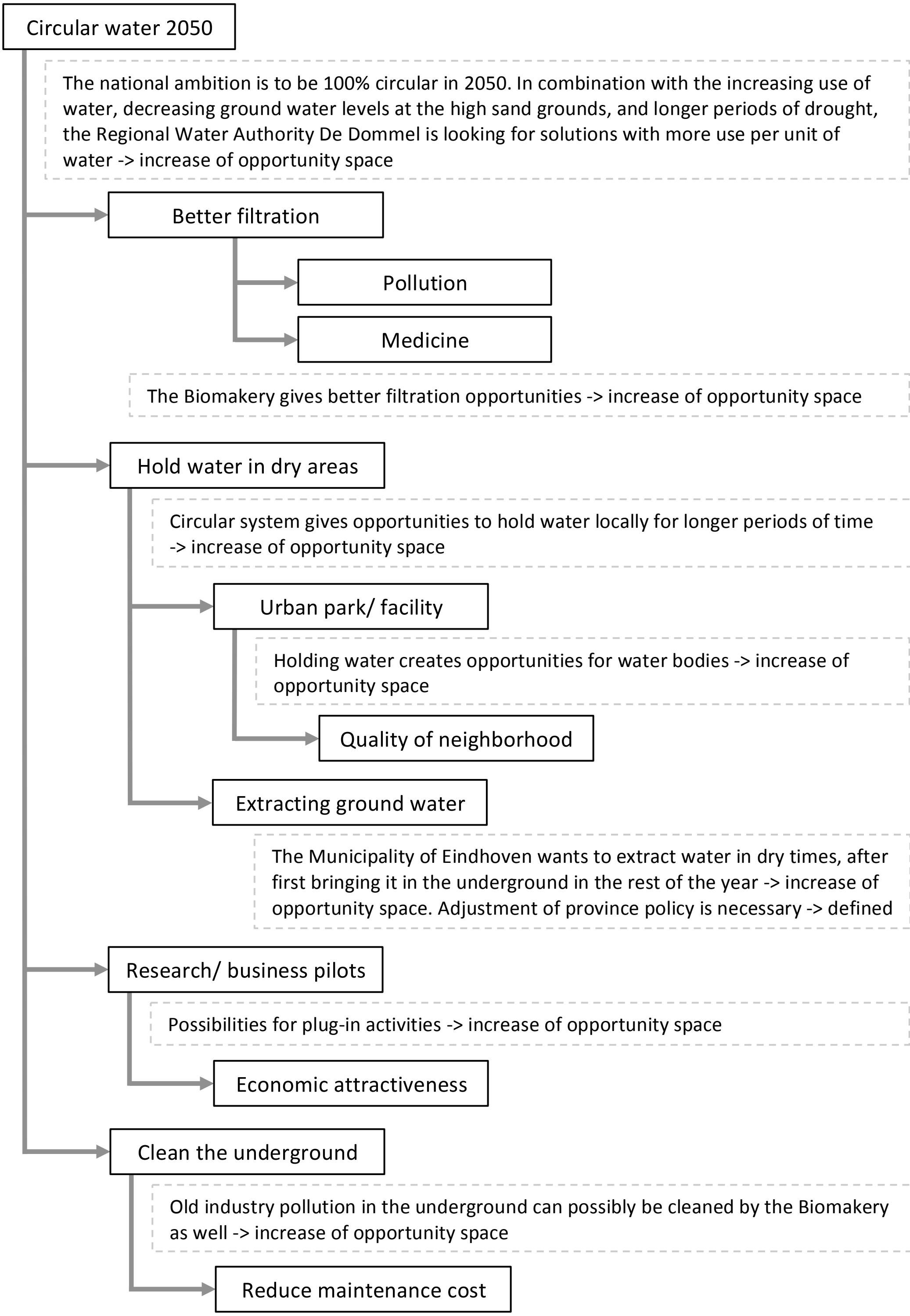


Figure 91 Cascading effect through integrated design for Biomakery Strijp-S

Although the delay in approval from the province, the municipality seems to become more in the lead of the project. The Biomakery could possibly support their two main interests and additional opportunities. This doubled-sided cascading effect with the interests of the municipality in the lead is schematized in Figure 92.

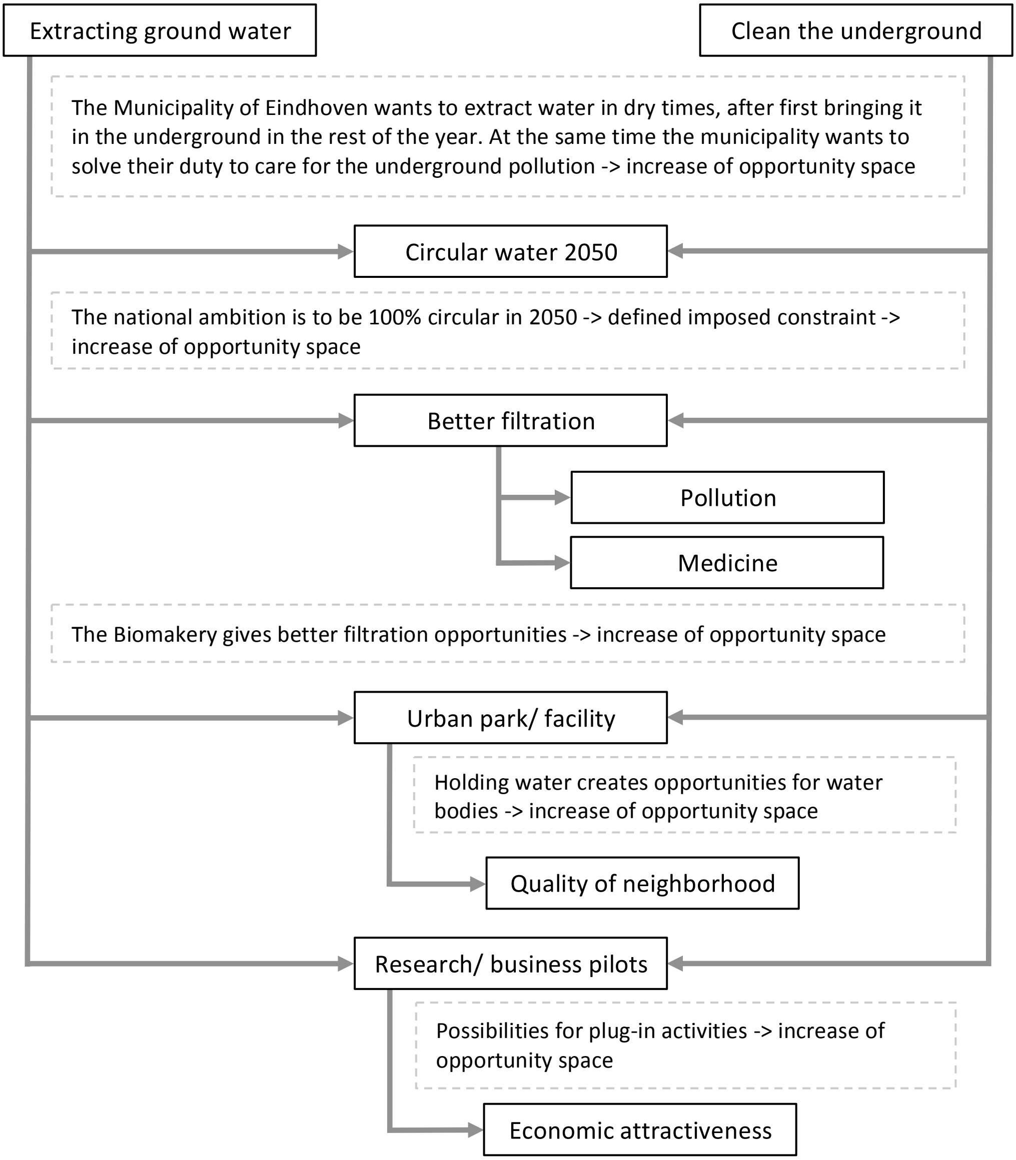


Figure 92 Double-sided cascading effect through integrated design for Biomakery Strijp-S

The schemes of Figure 91 and Figure 92 show that different forms of aspired value can become the dominant driver for the case. However, because of the lack of a defined program that has to be applied on the short term, the project lacks a leading stakeholder. The stakeholders are now looking at each other, while windows of opportunity are passing by.

6.5 Cross-Case Analysis

When the different researched cases are analyzed in perspective of each other, there are predominant similarities and differences that define the essential elements in shaping the window of opportunity for integrated design. An overview of these elements is schematized in Figure 93.

Leading defined program for solving problems forces momentum

First of all can be observed that in all researched cases, a defined program with corresponding budgets is essential for project progress. In addition, the defined program refers to solving a defined problem. For Coast Katwijk, flood risk reduction was the main problem in relation to the 'Hoogwaterbeschermingsprogramma'. For Benthemplein holds that flood risk reduction and the urgency to update the urban quality of certain city squares were the predominant motivation for integration. For Benthemplein holds that the Municipality of Rotterdam had to facilitate different functions, which came together in the concept of the water square. Finally, for Biomakery Strijp-S, the possible motivations for integration are related also related to problems of the need for circular water systems, increasing droughts, and polluted ground water. However, at the moment case Biomakery Strijp-S lacks a leading program on the short term. It can also appear that the different programs in relation to Biomakery Strijp-S are dependent on each other in terms of financial feasibility and therefore multiple programs should be in the lead. It seems that the lead in case Biomakery Strijp-S is shifting from the regional water authority to the municipality. Although the concept was initiated by the regional water authority to anticipate on the circular water plan 2050 and increasing filtration standards, it now seems that the interests of the municipality in extracting ground water and cleaning the underground becomes more critical on the short term.

Coast Katwijk can be stated as the clearest example of the researched cases in respectively sections 6.2, 6.3, and 6.4, with a defined program, namely the 'Hoogwaterbeschermingsprogramma'. From that program, a cascading effect of opportunities was possible for related stakeholders through integrated design. Although different opportunities that followed from the integrated design became part of the case, the 'Hoogwaterbeschermingsprogramma' remained the leading program and a driver of feasibility for the project. The 'Hoogwaterbeschermingsprogramma' only facilitated a window of opportunity and made participation of stakeholders and incorporation of additional forms of aspired value possible. The defined program of the 'Hoogwaterbeschermingsprogramma' forced momentum in that context. For Benthemplein and Biomakery Strijp-S hold that the projects actually appeal to defined problems, but start with the artifact concepts of respectively a water square and a biomakery. Although the concepts are related to solving problems, the search for a suitable place to apply the artifact appears to be a challenge. Without a dominant defined program in the lead, Benthemplein and Biomakery Strijp-S show or showed the search for dominant functions that may create windows of opportunity for additional functions. They even can be characterized by double-sided cascading effects in the case of the absence of a defined program with corresponding budgets to support a dominant function.

Room for frame abduction within leading program boundaries

With Coast Katwijk and Benthemplein as already completed projects, they both showed room for adjustments within the program boundaries. For example in case Coast Katwijk, the regional water authority was willing to hold to the physical boundaries of the base alternative and to adjust policies for the integration of other functions. This increased the window of opportunity and the opportunity space from a design perspective. There was room for so-called frame abduction, which means that the interpretation of the case within the program boundaries of the leading 'Hoogwaterbeschermingsprogramma' was part of the design itself. This led to the dune body with the 'dike in dune' alternative and parking garage underneath dune body. For case Benthemplein holds that the process incorporated frame abduction as well, because within the leading program boundaries, there was room for adjustments. The stakeholders and designers discussed and developed alternatives in order to come collaboratively to a final solution. In contrast, for Biomakery Strijp-S, the province is not willing to adjust policies to increase the window of opportunity till now. Without the presence of a defined program on the short term, and a dominant function and corresponding budgets that creates a feasible business case, the window of opportunity and momentum are lacking. Application of buffers in policies and labeling of budgets can possibly be supportive to the continuation and decision-making regarding cases of integration in case Biomakery Strijp-S.

Strategic incorporation of forms of aspired value

Another aspect that is illustrated in the researched cases is the possibility to apply integrated design as a means for strategic development. Case Benthemplein is the clearest example in this context. The regional water authority in case Benthemplein incorporated their interest in increasing visibility and water buffering in the inner city without land ownership, properties, or responsibility for maintenance and control. In that way, the regional water authority incorporated their interests in a strategic way, without large investments. Also the municipality incorporated the current capacity of water buffering of the square in their policy for that particular plot. In that way, the municipality can use their policies for local regeneration. Case Benthemplein shows that integration can also be used for strategic purposes to incorporate interests, even when a stakeholder is lacking ownership or investment opportunities. This is different for Coast Katwijk, in which the structure of the artifact was defined along institutional responsibilities and budgets, and the municipality financed the parking garage. For Biomakery Strijp-S holds that the regional water authority, municipality, and province all became financially responsible for one third of the project costs. However, additional partners such as knowledge institutes and property developers can benefit from possible developments without investments or institutional responsibilities regarding maintenance and control.

Aspired integration is context dependent
When it comes to integrated design, the cases show the context dependency of the aspired integration. For example, in case Coast Katwijk the integration is dependent on the scale level of the motivation for integration. The scale level of the dune body corresponds to the scale level of the motivation for integration in this case. In addition, the lifecycles of the 'dike in dune' and the parking garage differ probably, and the institutional responsibilities for flood risk reduction and parking differ. Therefore, the artifact design shows difference in structural integration on different scale levels. This scale level in relation to the scale level of the motivation can also be observed in case Benthemplein, in which water buffering and public space refer to the same scale level. In addition, the cascading effects in the researched cases show a functional hierarchy. In case Coast Katwijk, the dominant form of aspired value is flood risk reduction. In case Benthemplein the flood risk reduction is more critical than the public space for recreation, while a double-sided cascading effect can be observed. However, the relation between necessity and availability gives increases the opportunity space to facilitate both forms of aspired value in the artifact design of Benthemplein. For the Biomakery holds that the functional hierarchy is still under discussion and the lead seems to shift over different stakeholders with corresponding institutional responsibilities and forms of aspired value.

Human factor shapes mode of reasoning in project team
In the researched cases came forward that the definition and development of integrated design is strongly related to the mode of reasoning of people in the project team. In for example Coast Katwijk, the Mayor of Katwijk had a crucial role in the definition of the aspired value of parking. It can be stated that the definition of case Coast Katwijk was framed by an ambitious Mayor in the first place. This ambition on its turn shaped the window of opportunity and possible cascading effects. In addition, the project leader of the regional water authority carefully composed the project team with people that took with them the stakeholder management experience from project Maasvlakte II. The mix of personalities in the project team and the open attitude to the stakeholders made an effective and efficient process possible. Ideas from residents were taking into account, which increased the support for the project and the quality of the design and development. In addition, they also dared to increase the opportunity space due to the experience in former projects. From this experience, they knew how far they could go and stay in control at the same time. On the other hand, the project team was very clear to the participants. The project would be applied and gave them possible opportunities to incorporate. However, this required participation in the project process. The realization of the urgency and project schedule made the surrounding stakeholders more aware and participative.

Also Benthemplein worked in close collaboration with the surrounding stakeholders. After bad experiences in a former attempt to apply a water square, they actively looked for collaboration, in which residents were able to express their preferences regarding design in several sessions. In addition, the municipality took responsibility for the success of the project and covered responsibilities for maintenance for example. Biomakery Strijp-S did not come to this stage yet, because they first need an agreement with the different governmental stakeholders. However, also the human factor from the initiation is present in this project. The project initiator from the regional water authority investigated the possibilities for applying such a concept and therewith the project process took off. It has to be said that the human factor plays a big role in all projects. Although all researched cases showed the need to solve a problem and possible related defined programs, the willingness and ambition to incorporate more forms of aspired value is crucial for integration. It requires adjustment from traditional working principles, and people need the courage through experience, personal initiative and ambition, and support of their organizations to work on this. Without this mode of reasoning in the project team, the window of opportunity cannot be increased and the cascading effect cannot be utilized.

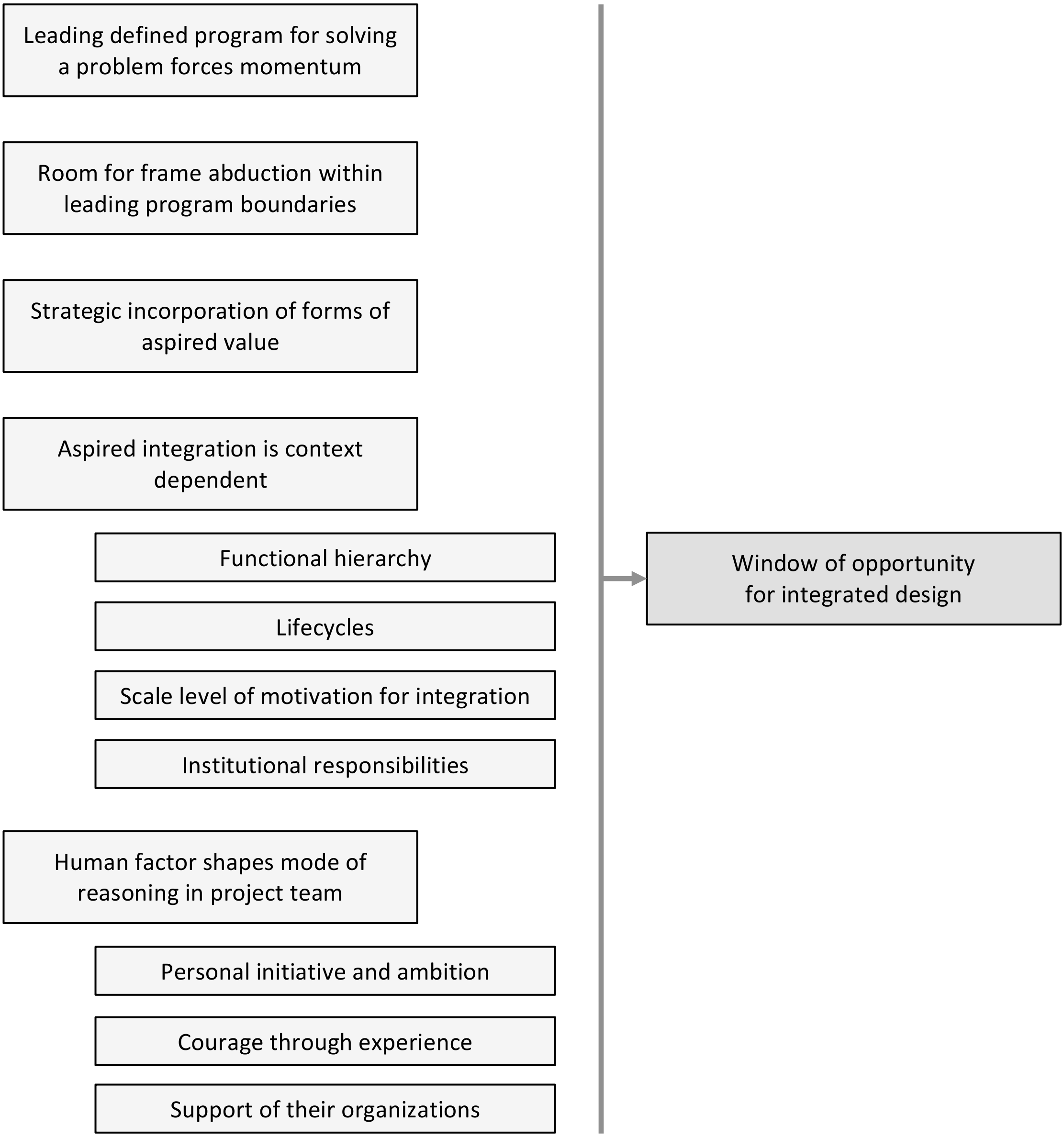


Figure 93 Elements that shape the window of opportunity for integrated design

6.6 Conclusions

Chapter 6 is related to research question 5 and corresponding sub-questions 5.1, 5.2, and 5.3. Research question 5 and sub-questions 5.1, 5.2, and 5.3 are in this context formulated as:

Research question 5:	What are the main findings from integrated design in practice?
Sub-question 5.1:	What is the motivation for integration?
Sub-question 5.2:	Which design aspects determine how the design is integrated?
Sub-question 5.3:	What are the conditions for the integrated design process?

To formulate a conclusion for research question 5, first sub-questions 5.1, 5.2, and 5.3 are discussed, before coming back to research question 5.

Sub-question 5.1: What is the motivation for integration?

The motivation for integration is researched for three cases, namely Coast Katwijk, Benthemplein, and Biomakery Strijp-S. For each of these cases the main motivation for integration will be described, supported by the themes that are defined for the different topics.

Coast Katwijk

The most prevailing motivation for integration in case Coast Katwijk was driven by the experience of conflicting interests in former places, such as Noordwijk and Scheveningen. This chronological benefit due to the fact Coast Katwijk was a non-priority project in the 'Hoogwaterbeschermingsprogramma' created opportunities for reflection and ideation. The lack of space between the city boulevard of Katwijk and the waterfront was a driver for integration of the parking garage and the 'dike in dune'.

Benthemplein

The motivation for integration at Benthemplein is twofold. First of all, the Regional Water Authority of Schieland en de Krimpenerwaard lacks resources in terms of land ownership in the inner city of Rotterdam. However, the regional water authority has its responsibilities regarding water management in the inner city. Therefore, the motivation for integration is driven by the lack of resources of the regional water authority. At the same time, the Municipality of Rotterdam has an ambition to increase the density of the city, which also motivates the integration of functions.

An additional important motivation is the desire of the regional water authority to create a showcase and raising public awareness on their responsibilities and activities. This was driven by a perceived lack of urgency of their work in the public and political domain. An integrated design of water buffering and public space could give shape to this idea of a showcase.

Biomakery Strijp-S

The motivation for integration in case Biomakery Strijp-S is driven by the desire to buffer water locally to solve the degenerative relation between the increasing local need for water and the shortage of water during dry summer months. This local ambition forced stakeholders to look for water solutions that can be applied within neighborhoods. At the same time, integration of the Biomakery creates opportunities for linking with other cases that are at stake at Strijp-S, such as treatment of the polluted ground water. While the project is at the moment in a process of reconfirmation, the linking and integration with other cases seems to become even an essential stake in the discussion towards governance agreement.

Sub-question 5.2: Which design aspects determine how the design is integrated?

The design aspects that determine how the design is integrated are researched for three cases, namely Coast Katwijk, Benthemplein, and Biomakery Strijp-S. For each of these cases the main design aspects that determine how the design is integrated will be described, supported by the themes that are defined for the different topics.

Coast Katwijk

The aspired integration of the parking garage and the primary sea defense from the motivation is context dependent. In case Coast Katwijk, the independent responsibilities and ambitions of the different stakeholders drove the choices in spatial and structural integration. First of all, the parking garage and the 'dike in dune' are constructed as different modules as part of the larger dune body on top. It illustrates that the aspired form of integration can differ on different scale levels. Therefore, the scale level and aspect from the motivation for integration have to be taken into account when it comes to defining the aspired integration.

In addition, there is a hierarchy in functionality. This hierarchy in functionality, and related risks and responsibilities in cases of interrelation, also adds to the design choices with respect to how the design is integrated. The primary sea defense should be available at all times, while the parking garage should be available as much as possible. The functional lifetime of the primary sea defense is directly related to the estimated safety for the City of Katwijk, while the functional lifetime of the parking garage is related to the accessibility of the City of Katwijk and the adjacent beach.

Benthemplein

The aspired integration is context dependent in case Benthemplein. The research into the design aspects that determine how the design is integrated shows that especially the hierarchy between functions shapes the aspired integration. For case Benthemplein holds that the water buffering function should always be available, but is only necessary a couple of times a year. On the other hand, the public function does not always have to be available. Even more, the capacity for water buffering is designed in such a way that the basins probably will be filled with rainwater a couple of times a year to increase the visibility of the relation between climate adaptation and the urban space. This also emphasizes the importance of the work of the regional water authority. However, the performance of the public function over time requires high maintenance efforts and costs, because the sediment is spread over the basin floors when filled with water. The first evaluation and recommendation for further development emphasizes applying different materials, floor shapes, or overflow systems to prevent the spread of this sedimentation.

Biomakery Strijp-S

A first design aspect that determines how the design is integrated is the feasibility of dominant functions. Although, initially less dominant functions such as the treatment of the ground water pollution become more dominant in the discussion towards governance agreement, the system should be able to substitute or becoming complementary to the already existing sewerage network. Wastewater treatment is the main function the Regional Water Authority De Dommel focuses on at the moment. For the regional water authority, the Biomakery at Strijp-S is also a project that is part of a larger program of Biomakeries in different places and for different clients. However, in this process, the political lifetime seems to be a bottleneck for progress. Elections on different governmental levels slow down the decision-making process. Subsequently, this influences on its turn possibilities regarding what can be integrated or not, because other programs have their own pace and timeline. At last, the stakeholders also reason from their own responsibilities, which makes that the design probably will be integrated in line with institutional responsibilities.

Sub-question 5.3: What are the conditions for the integrated design process?

The conditions for the integrated design process are researched for three cases, namely Coast Katwijk, Benthemplein, and Biomakery Strijp-S. For each of these cases the main conditions for the integrated design process will be described, supported by the themes that are defined for the different topics.

Coast Katwijk

One of the most important aspects regarding the conditions for the integrated design process is the momentum. First of all, the momentum in the form of the chronological benefit in the 'Hoogwaterbeschermingsprogramma'. In the second place also on the project level. The Regional Water Authority of Rijnland had already set their budgets for a traditional sober and effective solution, which meant more land reclamation than the creative alternative in the form of the 'dike in dune'. This created space and momentum for applying a parking garage behind the 'dike in dune'. In addition, the Municipality of Katwijk was willing to take the additional cost for constructing and maintaining the parking garage, while the Regional Water Authority of Rijnland was willing to adjust their policies to make this construction possible. The momentum is then formed by the people that are involved, and by the willingness of institutions to take responsibility or to change their policies.

An additional prevailing condition for the integrated design process was the strict organization of project management. The process was open for participation and ideas of stakeholders, but very strictly organized in time and procedures. Also the project team followed an open, but very strict organization. This well organized structure, and the fact that the integrated design was secured at a high level of detail to prevent falling back to traditional solutions during construction, formed essential conditions to obtain the aspired integration in the integrated design process.

Benthemplein

Because project Benthemplein was completed in 2013, this project also gives possibilities for evaluating the performance of the design and looking back at the process towards design, and maintenance and control afterwards. The first conclusion in this context is that the ad hoc approach for maintenance and control causes many new challenges. It is not always clear who is responsible for what. Because the Municipality of Rotterdam perceives a responsibility for keeping Benthemplein in good shape, it takes the responsibility for maintenance and control. However, the internal organization has difficulties to assign the municipal responsibilities with respect to Benthemplein to a certain department and related budgets. This is still under development.

During the design process of Benthemplein, the ad hoc approach was chosen from a strategic point of view to prevent putting emphasis on the possible high maintenance cost. This created space for the necessary internal commitment at the Municipality of Rotterdam at the time. The Municipality of Rotterdam also wanted to create this showcase. Open, but strategically information is therefore a condition for the integrated design process. Now, the Municipality of Rotterdam tries further developing this concept, and especially developing a structure to assign project responsibilities and budgets to different municipal departments. From their evaluation with respect to Benthemplein, the Municipality of Rotterdam now concluded that a recommended condition for the integrated design process in subsequent reference projects is a structure for maintenance and control.

Biomakery Strijp-S

In the project phase the Biomakery Strijp-S is at the moment, the main condition for the integrated design process is the momentum in stakeholder ambitions and involvement in relation to decision-making and governance. Different stakeholders have different ambitions and new governing boards can lead to new ambitions or changes in assigning budgets. Bringing together these ambitions and assignment of budgets of different stakeholders at a particular moment in time in which decision-making is required is a main condition for the integrated design process.

Research question 5: What are the main findings from integrated design in practice?

The main findings from integrated design in practice are in this dissertation described along three topics, namely 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. Sub-question 5.1, 5.2, and 5.3 are related to respectively topic a), b), and c), and researched and described for the cases Coast Katwijk, Benthemplein, and Biomakery Strijp-S. The conclusions with respect to research question 5 are based on the conclusions with respect to sub-questions 5.1, 5.2, and 5.3. The elements that are defined in relation to these three topics shape the window of opportunity for integrated design.

Conclusion motivation for integration
For the researched cases can be concluded that the motivation for integration is predominantly forced by the lack of space or resources. This forces stakeholders to think about a higher functionality per unit of space or resources, which motivates integration. Wit a lack of resources as the main driver for integrated design, program(s) are (re)defined to solve the problem in the researched cases. The (re)defined program in a particular case can force momentum to obtain a cascading effect of incorporating other functions through design. In that way, leading programs can increase the window of opportunity and increase the opportunity space from a design perspective. The researched cases show that the interventions solve problems en create opportunities at the same time.

Conclusion design aspects in relation to integration
How the design is integrated is context dependent. The main design aspects that determine how the design is integrated are the distinguished institutional responsibilities, lifecycles, and hierarchy in functionality. The tendency is to design and integrate functional modules in correspondence with the differentiation in modules of institutional responsibilities, lifecycles, and hierarchy in functionality. However, the motivation of integration determines on which scale level and for which design aspect functions are combined in one functional module.

In addition, integrated design can also be applied as a means for strategic development. When a stakeholder is lacking ownership, property, and/or power, the incorporation of forms of aspired value through design can be used strategically.

Conclusion conditions for the integrated design process
A first prevailing condition for the integrated design process is momentum. In the conclusion regarding the motivation for integration was already stated that leading program(s) can increase the windows of opportunity and force momentum.

However, a second condition related to this is that these programs come with opportunities for frame abduction and adjustments within the boundaries of the program. The challenge is to frame the integrated case in such a way that it attaches to larger leading programs, has a coupling with other projects, matches or adjusts policies, and becomes eligible for different budgets. Combining budgets can possibly create a positive business case. Bringing together the ambitions and budgets of stakeholders, and matching this with the different internal processes and pace of governance and decision-making through framing is an essential condition for the integrated design process.

A third main condition for the integrated design process is an ambitious project team with personal initiative and ambition, courage through experience, and support of their organizations. The researched cases show that the process to create an integrated design and maintain and control it over time is complex, because organizations have to act at the edges of their responsibilities and expertise, and in some cases even adjust their policies and governance structures. This requires personal commitment and courage of ambitious people with the experience to know how to act in such an integrated design process. This human factor shapes the mode of reasoning in the project team and drives framing in the case of integrated design.

7 Conclusions

This concluding chapter is looking back at the main question of this research:

> *'How can integrated design be translated into a framework for semantic, methodological, and practical application?'*

The framework for integrated design will be constructed from the conclusions with respect to the defined research questions, for which an overview per research part is given in Figure 94.

Framework Integrated Design	Theoretical Framework	**Part I: Semantics Integrated Design**		
			Research question 1:	What is integrated design?
			Research question 2:	How can integrated design support solving issues of integration?
		Part II: Methodology Integrated Design		
			Research question 3:	What is the relation between the methodological structure and the definition of the design space for integrated design?
			Research question 4:	How can a meta-method for integrated design support solving issues of integration?
	Practice	**Part III: Integrated Design in Practice**		
			Research question 5:	What are the main findings from integrated design in practice?

Figure 94 Overview of the research questions per research part

The conclusions with respect to the research questions 1 to 5 are presented from this point to construct the conclusion for the main research question. The conclusions for research questions 1 to 5 correspond in description with the conclusions of section 2.4, section 3.4, section 4.4, section 5.4, and section 6.6 to prevent discussion between different descriptions of the conclusions.

Part I: Semantics Integrated Design

Research question 1: ***What is integrated design?***

The term 'integrated design' is defined as the 'framing of the compatibility of multiple artifact frames'. The terms in this definition appeal to a terminological common ground in order to discuss and develop integrated design. Integrated design is in this dissertation used as a descriptive term for the framing of the interrelation between different artifact frames. The interrelation between these artifact frames can be described along five levels of compatibility. In this context, the definition of reference states and corresponding intervention is framing the compatibility of different artifact frames.

Research question 2: ***How can integrated design support solving issues of integration?***

Issues of integration can appear when different artifact frames limit each other's space to incorporate value in the case of integration. The compatibility of different artifact frames can be described along five levels. In relation to integrated design, compatibility level 1 to 4, all refer to conflicting constraints in the construction of the space to incorporate value. Compatibility level 5 is different from compatibility level 1 to 4, because in the case of integrated design in accordance with compatibility level 5, value conflicts and the lack of possibilities to incorporate value can be dissolved.

To (re)frame the interrelation between different artifact frames, the constraints that define the combined design space should be reflected on a typology of constraints. Three types of constraints are defined, namely 'intrinsic', 'imposed', and 'self-imposed' constraints. 'Imposed' and 'self-imposed' constraints can be subordinate to design themselves, when they are in the scope of control of the designer. When the constraints that define the design space are partly subordinate to design, it implies that the compatibility of different artifact frames can also be subordinate to design. When a designer is able to create integration between interrelated artifact frames in accordance with compatibility level 5, the designer is also able to dissolve constraints that limit the space to incorporate value with respect to these interrelated artifact frames.

Integrated design can support solving issues of integration when mutually incompatible constraints can be (re)framed in such a way that artifact frames become compatible in accordance with compatibility level 5. In that case, issues of integration will be dissolved and a state of abundance with respect to the relation between different forms of aspired value can be created.

Part II: Methodology Integrated Design

Research question 3: ***What is the relation between the methodological structure and the definition of the design space for integrated design?***

A spectrum of abduction with respect to different modes of reasoning in design can be defined. Different fields of design are predominantly related to 'defined abduction' or 'frame abduction', which differentiates design in respectively design with a defined artifact frame, and design in which the definition of the artifact frame is part of the design itself. The methodological structure frames reasoning in the design process along the spectrum of 'defined abduction' to 'frame abduction'.

With integrated design defined as the 'framing of the compatibility of multiple artifact frames', 'defined abduction' implies integrated design as the 'framing of the compatibility of multiple defined artifact frames'. This means that the level of compatibility between multiple artifact frames is also already defined for 'defined abduction'. The definition of the design space for integrated design is framed by the definition of the compatibility between multiple artifact frames and is therewith defined as well. Methodological structures that are predominantly related to 'defined abduction' are therefore related to the definition of the design space for integrated design in a context of a defined compatibility of multiple artifact frames.

For 'frame abduction', the definition of the artifact frame is part of the design itself. This means that the 'framing of the compatibility of multiple artifact frames' is subordinate to design for 'frame abduction'. Methodological structures that are predominantly related to 'frame abduction' are therefore related to the definition of the design space for integrated design in a context of a compatibility of multiple artifact frames that is part of the design itself.

The different relations between the methodological structures and the definition of the design space for integrated design will also result in different perspectives on integrated design. When artifact frames are predefined, integrated design will focus on the integration of the actual artifacts, which can be marked as a technical interpretation of integrated design. When the definition of the artifact frames is part of the design itself, integrated artifact frames can lead to new typologies of artifacts, which can be marked as a more conceptual interpretation of integrated design. To what extent the artifact frames are predefined or part of the design itself, frames the definition of the design space for integrated design, and therewith also the interpretation of integrated design.

Research question 4: How can a meta-method for integrated design support solving issues of integration?

When incompatible artifact frames cause issues of integration, a designer can use the meta-method to identify the artifact frames and their typology of constraints. In this way, the designer can increase frame awareness and identify opportunities to frame different forms of aspired value and corresponding working principles. Additionally, the meta-method also supports the search for, and definition of common values. Forms of aspired value can conflict, but underlying values do not have to conflict. From common values, working principles and forms of aspired value can be (re)defined through a process of co-evolution. The meta-method methodologically structures the design process of divergence and convergence, in order to find and define a common ground for integration, and to obtain compatibility level 5 for the relation between different artifact frames. The integrated design process is a co-evolutionary and short cyclic iterative process, with feedback loops within and between the design steps. The translated design phases and design steps that represent a meta-method for the act of design in the conceptual approach are formulated as:

Frame awareness:
1) Identifying different artifact frames
2) Identifying a typology of constraints

Designer framing:
3) Translating aspired value into values
4) Defining common working principles and forms of aspired value

The meta-method can be used by designers in different disciplines, for different fields of application, to support solving issues of integration. In addition, the meta-method can be used to develop an integrated design approach for a particular field of application. Finally, it also forms a platform for discussing methodological structures for integrated design with respect to the act of design in the conceptual approach. The meta-method for integrated design is not intended to replace currently used methodological structures in different fields of design, but as an additional method that can be used in parallel to support solving issues of integration.

Part III: Integrated Design in Practice

Research question 5: What are the main findings from integrated design in practice?

The main findings from integrated design in practice are in this dissertation described along three topics, namely 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. The elements that are defined in relation to these three topics shape the window of opportunity for integrated design.

Conclusion motivation for integration

For the researched cases can be concluded that the motivation for integration is predominantly forced by the lack of space or resources. This forces stakeholders to think about a higher functionality per unit of space or resources, which motivates integration. With a lack of resources as the main driver for integrated design, program(s) are (re)defined to solve the problem in the researched cases. The (re)defined program in a particular case can force momentum to obtain a cascading effect of incorporating other functions through design. In that way, leading programs can increase the window of opportunity and increase the opportunity space from a design perspective. The researched cases show that the interventions solve problems en create opportunities at the same time.

Conclusion design aspects in relation to integration

How the design is integrated is context dependent. The main design aspects that determine how the design is integrated are the distinguished institutional responsibilities, lifecycles, and hierarchy in functionality. The tendency is to design and integrate functional modules in correspondence with the differentiation in modules of institutional responsibilities, lifecycles, and hierarchy in functionality. However, the motivation for integration determines on which scale level and for which design aspect functions are combined in one functional module.

In addition, integrated design can also be applied as a means for strategic development. When a stakeholder is lacking ownership, property, and/or power, the incorporation of forms of aspired value through design can be used strategically.

Conclusion conditions for the integrated design process
A first prevailing condition for the integrated design process is momentum. In the conclusion regarding the motivation for integration was already stated that leading program(s) can increase the windows of opportunity and force momentum.

However, a second condition related to this is that these programs come with opportunities for frame abduction and adjustments within the boundaries of the program. The challenge is to frame the integrated case in such a way that it attaches to larger leading programs, has a coupling with other projects, matches or adjusts policies, and becomes eligible for different budgets. Combining budgets can possibly create a positive business case. Bringing together the ambitions and budgets of stakeholders, and matching this with the different internal processes and pace of governance and decision-making through framing is an essential condition for the integrated design process.

A third main condition for the integrated design process is an ambitious project team with personal initiative and ambition, courage through experience, and support of their organizations. The researched cases show that the process to create an integrated design and maintain and control it over time is complex, because organizations have to act at the edges of their responsibilities and expertise, and in some cases even adjust their policies and governance structures. This requires personal commitment and courage of ambitious people with the experience to know how to act in such an integrated design process. This human factor shapes the mode of reasoning in the project team and drives framing in the case of integrated design.

Main research question: How can integrated design be translated into a framework for semantic, methodological, and practical application?
The framework for integrated design, as described in this dissertation, consists of three main parts, namely 'Semantics Integrated Design', 'Methodology Integrated Design', and 'Integrated Design in Practice'. As part of this larger framework for integrated design, the 'Semantics Integrated Design' and 'Methodology Integrated Design' form on their turn the theoretical framework. In addition to the theoretical framework, a perspective from practice adds complementary points of attention and insights regarding integrated design.

As derived from the exploratory research that was presented in this dissertation, the main conclusions with respect to the research questions 1 to 5 are formulated as 10 principle notes that construct the framework for integrated design. Figure 95 gives an overview of the 10 principle notes in relation to the different parts of the framework for integrated design. The T-shaped professional should be skilled in defining, discussing, and developing the 10 principle notes of Figure 95. The framework for integrated design can in that case be applied as a platform for semantic, methodological, and practical discussion and development.

Framework Integrated Design

Theoretical Framework

Semantics Integrated Design

1) Integrated design is the framing of the compatibility of multiple artifact frames

2) There are different types of constraints: intrinsic - imposed - self-imposed

3) Integrated design -> compatibility level 5 -> dissolution -> abundance

Methodology Integrated Design

4) The act of design in integrated design is formed by the interplay of defined abduction and frame abduction

5) Meta-method for integrated design:
   Frame awareness
   1) Identifying different artifact frames
   2) Identifying a typology of constraints

   Designer framing
   3) Translating aspired value into values
   4) Defining common working principles and forms of aspired value

Practice

Integrated Design in Practice

6) Force momentum by defining a leading program

7) Create room for frame abduction within leading program boundaries to solve issues and to create opportunities in relation to budgets and policies

8) How the design is integrated depends on the functional hierarchy, lifecycles, scale level of motivation for integration, and institutional responsibilities

9) An ambitious project team with personal initiative and ambition, courage through experience, and support of their organizations is key regarding the mode of reasoning in the integrated design process

10) Integrated design can be applied as a means for strategic incorporation of forms of aspired value when lacking power and/or property

Figure 95 Overview of principle notes that construct the framework for integrated design

8 Discussion

8.1 Reflection on Aims of this Dissertation

This chapter 8 starts with a reflection on the research in relation to the stated aims in section 1.4. The main aim of this dissertation was to develop a framework for integrated design in order to form a platform for semantic, methodological, and practical discussion and development. The research was organized as an exploratory research, because a first investigation showed several scientific gaps with respect to a description of the fundamentals of integrated design. These fundamentals are in this dissertation described as different building blocks, which refer to the 5 defined aims that construct the main aim. These 5 aims are numbered in correspondence with the numbers of the defined research questions:

1) A description and definition of integrated design as a terminological common ground for discussion about integrated design (research question 1)
2) A conceptual approach that presents how integrated design can support solving issues of integration (research question 2)
3) Overview of the relation between framing in different fields of design and the definition of the design space for integrated design (research question 3)
4) A meta-method for integrated design (research question 4)
5) The main findings from integrated design in practice (research question 5)

Looking at the aims of this dissertation can be stated that the content of the conclusions matches with the different aims. In addition, concluding chapter 7 presents a framework for integrated design, which is constructed from the different building blocks. The framework for integrated design as presented in chapter 7 appeals to the main aim of this dissertation.

In the sequential sections 8.2, 8.3, and 8.4, respectively the 'reliability', 'internal validity', and 'external validity' will be at stake. The 'reliability', 'internal validity', and 'external validity' of this research are described for the 'semantics integrated design', 'methodology integrated design', and 'integrated design in practice'. At last, further research will be discussed in section 8.5.

8.2 Reliability

Reliability Semantics Integrated Design

The research into the semantics of integrated design was conducted through researching peer-reviewed articles and books. The incorporated peer-reviewed articles and books represent influential and broadly cited publications in design sciences in most cases. A broad investigation of literature was executed to obtain a broad view of the different definitions and related terms.

Reliability Methodology Integrated Design

Responsible teachers and coordinators of design education at different faculties of Delft University of Technology were consulted to find the methodological structures as used at these faculties. The conversations with the responsible teachers and coordinators all took place within the period of about half a year. This created a decent base to compare different design education programs. The methodological structures were differentiated in design process models and design methods. These were related to the spectrum of abduction to describe the different modes of reasoning in design at the investigated faculties. Finally, a couple of years later than the first conversation moment, the responsible teachers and coordinators were again consulted if the described methodological structures per faculty are still valid. In addition they were asked to their perspective on the described dominant mode of reasoning in design at their faculty. The interval of years between the first and the second moment of consultation is an indicator for the embedment of the methodological structures and corresponding modes of reasoning in design at the investigated faculties. Some new teachers or coordinators were involved the second time, and where necessary, adjustments regarding the description of the methodological structures and modes of reasoning were made.

The research into a common ground in integrated design approaches was executed by researching peer-reviewed articles and books. The literature regarding the integrated design approaches was partly obtained during the literature research in the semantics part. Additionally found integrated design approaches were added to the research in chapter 5.

Reliability Integrated Design in Practice

In the discussion of the reliability of the integrated design in practice part, the main focus is on the interviews. The interviews took about one to one and a half hour, and were recorded. After the interviews, a manual transcription of the interviews was made as the English translated version of the Dutch interview. In the transcriptions, the search was to balance between a literal transcription and a satisfying English translation, to give a representative impression of the interviews. The transcriptions were on their turn also sent to the interviewees for feedback and acceptance.

All the interviews for the different cases and transcriptions, including the time for feedback and acceptance, were executed within the period of a half a year. This was also done to get an impression of the case at a relatively particular moment in time, without possible large differences in information or new insights over time. Therewith this research part can be typed as a cross-sectional research. To attach representative codes to the interviews, the context of the interview sections to which the codes referred to were always taken into account. However, it can still be discussed if certain parts of the interview refer to multiple codes and categories. There can be overlap between different codes and between different categories in that context. To submit this research therefore to a short review, another researcher of Delft University of Technology, who is independent and knowledgeable in the design sciences, was asked to have a look at samples of coded transcriptions. After an introduction into the line of reasoning behind the coding and categorization of the transcriptions, this researcher had a look at the samples of all interviews. The coding schemes for the cases Coast Katwijk, Benthemplein, and Biomakery Strijp-S can be found in respectively Appendices C.1, C.2, C.3.

The inter-rater reliability of the coding of the transcribed interviews in case Coast Katwijk is 91 percent. The inter-rater agreed on the summed 43 of the 47 reviewed codes from the samples.

The inter-rater reliability of the coding of the transcribed interviews in case Benthemplein is 95 percent. The inter-rater agreed on the summed 39 of the 41 reviewed codes from the samples.

The inter-rater reliability of the coding of the transcribed interviews in case Biomakery Strijp-S is 85 percent. The inter-rater agreed on the summed 68 of the 80 reviewed codes from the samples.

The found percentages regarding the inter-rater reliability for the coding of the transcribed interviews in the cases is relatively high, but a factor in this is that the choice was made to review the given codes by the inter-rater instead of formulating codes on itself. This was done because the high level of detail of the coding schemes. The inter-rater was therefore asked to have a look if the codes within their categories were formulated appropriately in correspondence to the samples of the transcribed interviews.

8.3 Internal Validity

In General

Limited bias at the start

The author of this dissertation, which is also the researcher, did not have a background or experience in design sciences before the start of this research. The supervisors of the author also created an atmosphere of free decision-making regarding the design of this research to serve its exploratory character. The author of this dissertation was not prejudiced or influenced by dominant theories on beforehand. Therefore, setting up the research questions and investigating the broad field of theories took some time, but was done with an open attitude and served the exploratory character of this research.

Layered structure of research

The structure of the research as presented in this dissertation contains interdependent layers. In addition, the structure of the research and corresponding research questions contain an extensive breakdown structure. The main question is differentiated in five research questions, which are each on their turn differentiated in two or three sub-questions. Through the sub-questions, the research goes more in-depth and gives more context regarding the conclusions in the different chapters.

The structure of the research is sequentially formed by the 'what', 'why', and 'how' of integrated design. The first two parts are related to the theoretical framework. The research into integrated design in practice in the third part adds a practical perspective to this, and constructs together with the theoretical framework the larger framework for integrated design. The layered structure of the research is constructed carefully to structure exploration in valid layers that built upon each other.

Feedback from supervisors during the research process
Two main supervisors toke responsibility for giving feedback during the process of this research, both in content and structure. They are both leaders in their research fields. In addition, the two supervisors have complementary profiles in terms of research fields, research communities, and background. This complementary setting was chosen on purpose to expose the research results to different perspectives in order to increase the validity.

Internal Validity Semantics Integrated Design
Research question 1: 'what is integrated design?' was differentiated in sub-question 1.1: 'how can design be defined?', and sub-question 1.2: 'how can integrated be defined?'. 'Integrated' can be stated as an addition of 'design'. Therefore, a definition of design was researched before a definition of integrated. This also gives more context to the term 'integrated' in relation to different fields of design. The amount of found definitions or ways to describe 'design' and 'integrated' or 'integration' in relation to 'design' is not essential to obtain a valid research, because the goal was to find a common ground in the definitions and descriptions. However, a broad overview of definitions represents different perspectives and increases the internal validity with respect to a definition of integrated design.

The exploratory research of research question 1 and corresponding sub-questions 1.1 and 1.2 was done through literature research, consisting of looking for publications via online searching machines and looking for references in found publications. The main focus was on peer-reviewed articles and books. The peer-reviewed articles and books were in the first place scanned on containing the terms 'design', and 'integrated' or 'integration' in combination with the term 'design'. References in the found publications elaborated the literature research and added nuances or additional fields of application in design.

Research question 2: 'how can integrated design support solving issues of integration?', which was presented in chapter 3, was also investigated through literature research. Again online searching machines were used to obtain peer-reviewed articles and books.

Regarding both research question 1 and research question 2, the descriptions were built on, or related to, embedded frameworks to describe for example different levels of compatibility or different types of constraints. These frameworks are in this research used to support the description of integrated design, or used in relation to integrated design, without fundamentally changing the frameworks themselves.

Internal Validity Methodology Integrated Design

Chapter 4 was related to research question 3, which was formulated as: 'what is the relation between the methodological structure and the definition of the design space for integrated design?'. Different faculties of Delft University of Technology that are related to the design of an artifact were investigated on their methodological structures. To obtain more context of the origins of these methodological structures, literature research was done into different schools of design and corresponding modes of reasoning in design. This literature research was conducted through the use of online searching machines to obtain peer-reviewed articles and books. The references in these books were used to obtain additional articles and books. With more knowledge about the origins of current methodological structures, assumptions and fundamentals of different modes of reasoning came forward, which were translated into a spectrum of abduction in this dissertation.

For the investigation of the different modes of reasoning in design at different faculties, the research was bounded to faculties that are related to the design of an artifact. Although there can be discussed if additional faculties should be investigated, because they are also related to the design of an artifact, this is not essential in the context of this research. The goal of the research was to get an overview of methodological structures in relation to different modes of reasoning in design, and subsequently the definition of the design space for integrated design.

The different methodological structures were obtained by consulting responsible teachers and coordinators of design education at the investigated faculties. Consultation comprehends providing study material as used in the different design courses, showing used books and readers, and providing lecture slides. The conversations with the responsible persons were always at the location and moment as proposed by this person.
The design methods, as part of the investigated methodological structures, were described in relation to the spectrum of abduction. These design methods were positioned on the spectrum of abduction, although the exact position can be discussed. However, the exact presentation on the spectrum of abduction illustrates the modes of reasoning in design at the different investigated faculties, which adds to the aim of chapter 4. Therefore the choice was made to present the design methods in this way on the spectrum of abduction, including the notion that the exact position of the design methods can be discussed. The way the design methods are presented on the spectrum of abduction does not seem to decrease the internal validity, because the goal was to obtain insight in the modes of reasoning in design at the different investigated faculties.

For research question 4: 'how can a meta-method for integrated design support solving issues of integration?', the research into the definitions for 'design' and 'integrated' and 'integration', as described in chapter 2, also gave input to the research into different integrated design approaches. In addition, literature research into possible interchangeable terms regarding 'integrated' and 'integration' showed related design approaches. Subsequently, online searching machines were used to obtain peer-reviewed articles and books about different integrated design approaches that are related to the found terms. In addition, the research into methodological structures at different faculties of Delft University of Technology was also useful in getting a broader overview of different design approaches. Some faculties incorporate certain integrated design approaches in tracks of their Master's program. For example the faculty of Civil Engineering and Geosciences has a track in its Master's program that is related to Building with Nature.

The, as in this dissertation called, integrated design approaches that are related to compatibility level 5 were further researched in the sequence of chapter 5. The number of integrated design approaches, or an all-comprehensive research into integrated design approaches, was not the goal of this research. The goal was to find a common ground in a broad field of applied integrated design approaches.

Internal Validity Integrated Design in Practice

The research into research question 5: 'what are the main findings from integrated design in practice?' was executed by doing three case studies of a comparable scale, related to the domain of civil infrastructure, and all located in The Netherlands. This was done to be able to compare them and finding complementary aspects within the domain of civil infrastructure. In addition, civil infrastructure is also the predominant domain for research in the Deltas Infrastructure and Mobility Initiative (DIMI). Choosing cases that are all located in The Netherlands also gave possibilities for comparing them for the involvement of different institutions and it was simply easier to obtain more data and information about these cases. The, in general, collaborative relation between knowledge institutes, governments, and businesses in The Netherlands does not automatically have to available in an international context. Therefore, these three cases seemed to be suitable for this research. In the national context these cases got public attention and even awards over time, which led to more publications, data, and information about these cases and therewith opportunities to research different sources to increase the validity of this research. The three cases are in different phases of their lifetime, which gave an extra dimension to obtain complementary perspectives.

The three cases studies were researched through a triangulation of different sources. First of all, interviews were done with several involved professionals of the cases. The professionals had different roles in the cases and were related to different organizations. However, all interviewees had a leading role in the particular case. This helped to obtain information about the motivation, design choices, and the design process of the case. For case Coast Katwijk, five interviewees participated in the research, for case Benthemplein three interviewees, and for case Biomakery Strijp-S five interviewees. The number of interviewees was a bit smaller for case Benthemplein, because the Municipality of Rotterdam took the responsibility for many aspects of the case, so therefore the information regarding these aspects was available at this stakeholder. Secondly, the interviewees were asked for supportive documents and presentations in relation to their story. In the third place, also online searching machines were used to obtain public information about the cases. The cases are therewith described on the base of multiple sources of information.

The interviews were structured as open-interviews in which three main topics came along, namely 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. Sub-question 5.1, 5.2, and 5.3 were related to respectively topic a), b), and c), and researched and described for the cases Coast Katwijk, Benthemplein, and Biomakery Strijp-S. Open-interviews with the incorporation of these three topics served the exploratory character of this research, but also directs towards answers with respect to sub-questions 5.1, 5.2, and 5.3. The interviews were done in Dutch at the location and time that was proposed by the interviewee. This supported the comfort of the interview for the interviewees.

Researched and elaborated terms from the theoretical framework of this research were not used in the interviews. This was done to create an open atmosphere without confusing interviewees with terminology they are possibly not used to. 'Integrated design' was used as a term in the interviews, but not in its definition from the theoretical framework. In addition, it was also not necessary to use the terminology from the theoretical framework for an interview about the topics that were mentioned.

The transcriptions of the interviews were marked in the three mentioned categories 'a) motivation for integration', 'b) design aspects in relation to integration', and 'c) conditions for the integrated design process'. Sometimes, interviewees also added elaborations on other cases or the broad organizational policy, which could confuse the research with respect to coding. Therefore, the marking in the transcription document did not incorporate these elaborations and these parts were therefore not incorporated with respect to the coding.

The transcription parts that were marked were coded, and the codes categorized. The different categories were given more content with the definition of sub-themes, and finally themes, which presented the main points from the interviews. The relatively high percentages with respect to the inter-rater reliability showed that, although the inter-rater reviewed the given codes within the categories for samples of all transcribed interviews instead of formulation them on itself, the coding formed an appropriate fundament for formulating themes along which the researched cases could be described.

It happened that interviewees paid more attention to case aspects in relation to for example the category 'preparation' during the interview. This was in many cases because their specialty or role in the case was related to this category. In addition, as already mentioned with respect to the reliability, it can be discussed if certain parts of the interviews refer to multiple codes and categories. The codes and categories show overlap in that context. However, because the coding and categorization was done to describe the cases along a scientific structure, the overlap is not limiting the internal validity. The number of times a certain code is given, or to how many codes a part of the interview refers, was not the main point of this research, and therefore not significantly influencing how the case is described. Therefore, the complementary roles and corresponding points of attention of the interviewees do not diffuse the research results, but support a broader and more comprehensive description of the cases.

8.4 External Validity

In General

Modular application of framework for integrated design

The structure of building blocks that construct the framework for integrated design gives room for applying different parts for different purposes. Therewith, not the complete framework for integrated design has to be applied in every case, but elements of this framework are suitable to apply as well.

External Validity Semantics Integrated Design

The research into research question 1: 'what is integrated design?' shows that to fulfill a platform function, integrated design should be non-normative. 'Integrated' is therefore used as a descriptive term to describe the relation between for example different aspects, functions, systems, or elements.

The use of 'integrated' as a descriptive term also shifts the discussion if something is integrated 'good' or 'bad' to the discussion how something is integrated. This in contrast to a term such as 'integral', which is referring to a normative frame. In this dissertation, the line of reasoning is that the normative frame in relation to how something should be integrated can be given by the stakeholders. This makes the framework less sensitive for different cultural and time-dependent normative perspectives. In addition, the use of 'integrated' as a descriptive term also dissolves the discussion if something is integrated or not, to a discussion if something is integrated in a desirable or undesirable way in relation to the normative frame of the stakeholders.

Research into interchangeable terms also shows the overlap and difference with related terminology. In this way, the platform function of the framework for integrated design can be broadened to design fields in which terms as 'integrated' and 'integration' are not that commonly used. Integrated design can then be discussed in relation to these related terms.

Another aspect is the definition of the term 'design'. In a long tradition of attempts to define design there is not one dominant term that is adopted by different fields of design. Therefore, the search was to find common ground in the definitions of design, in such a way different fields of design can discuss and develop this further with the support of the framework for integrated design.

The conceptual approach for solving issues of integration is built on terminology and concepts that are suitable to adopt in different disciplines, which also serves the platform function of the framework for integrated design.

External Validity Methodology Integrated Design

Looking at the investigation of design at different faculties of Delft University of Technology in chapter 4, the differentiation in design appeals to the discussion about the border between 'engineering' and 'design'. To move away from this discussion, this dissertation focuses on a more abstract level of modes of reasoning in design, as Dorst (2011) does in his scheme. In this dissertation, design is therefore described along a spectrum of abduction, ranging from 'defined abduction' to 'frame abduction'. 'Defined abduction' is referring to design within a defined artifact frame, and 'frame abduction' is referring to design in which the definition of the artifact frame is part of the design itself. In this way, the term design can be applied in a broader context to support the platform function of the framework for integrated design.

The research focused on interpretations of design at different faculties of Delft University of Technology. However, in conversations and meetings with academic design experts it seems that the methodological structures per faculty are characterizing the design fields in a broader context than Delft University of Technology. Therefore, it seems that the framework for integrated design is applicable in different design fields outside the investigated faculties of Delft University of Technology as well, although this cannot explicitly concluded from the research.

The meta-method for integrated design is constructed from the common ground in existing integrated design approaches. Described in the terminology of chapter 2, the meta-method for integrated design can be applied in multiple design fields. The meta-method was intended in complementary to currently applied methodological structures. Therewith, the meta-method does not replace currently applied methodological structures in different design fields, but can be applied in parallel to support solving issues of integration. In addition, the meta-method also serves as a platform for discussion and development of the methodology with respect to integrated design.

External Validity Integrated Design in Practice

The selected cases for this research are all civil infrastructure cases. Therefore, the framework for integrated design can be limited to the field of civil infrastructure for the practical part. The cases show overlap in the way that they are all located in The Netherlands. Therefore, the external validity can be stated as limited to the field of civil infrastructure in The Netherlands. In addition can be said that the cases are all related to water challenges. However, water challenges in relation to primary sea defenses, urban water, and wastewater treatment are different type of challenges. Nevertheless, the research as presented in this dissertation showed that many themes with respect to integrated design are comparable for the different cases. This shows that although the different types of water challenges in the researched cases, the main findings from integrated design in practice are comparable. Therefore, it can be assumed that the notes that were described regarding integrated design in practice are of interest in additional cases in the field of civil infrastructure in The Netherlands as well.

8.5 Further Research

First of all, further research could focus on the interdisciplinary team setting and the way the interplay of defined abduction and frame abduction can be organized. The research could then be about the relation between the application of the framework for integration design and the collaboration of team members from different disciplines. This can support project managers in composing teams for cases of integrated design.

Second, further research might explore the inter-academic context of the research results. For this research, the methodological structures for different faculties of Delft University of Technology are investigated. It would be interesting to research the methodological structures of additional faculties, or faculties or design schools at other universities. This can broaden the field of application, and increase the reach of the framework for integrated design.

As a third effort of further research could focus on inter-practical context, in which additional cases in the field of civil infrastructure or other fields of application could be investigated. This can broaden the reach of the framework for integrated design to more fields of application. In addition, also cases on different scales, and with more or less stakeholders can be researched to obtain more insight into integrated design in practice.

A fourth suggestion for further research is the international and intercultural context of integrated design. Different cultural paradigms regarding for example interpretations of design, methodological structures, and case studies can be reflected on the framework for integrated design as presented in this dissertation. Additional research into the international and intercultural context of integrated design can be linked to international cases in which different cultures between countries come together.

Finally, a fifth effort of additional research could add to the embedment of the framework for integrated design. Especially the elaboration of more examples in relation to the conceptual approach, which is described in chapter 3, would be helpful. At the moment, some example cases are described to explain the line of reasoning in the conceptual approach. Additional examples could present and test the line of reasoning in the conceptual approach for embedding the framework for integrated design.

Presenting and testing the applicability and line of reasoning is also at stake for the meta-method for integrated design, which is described in chapter 5. The development of integrated designs with the support of the meta-method can show the applicability of the meta-method. Insights in which context the conceptual approach and the meta-method are more or less applicable would support further development and embedment of the framework for integrated design.

9 Recommendations

The recommendations are divided in 'General Recommendations', 'Recommendations for Academics', and 'Recommendations for Practitioners', and will be described in this sequential order from this point.

General Recommendations

- Use 'integrated design' as a descriptive and non-normative term. In this way, integrated design becomes less sensitive for time-dependent normative perspectives and knowledge. In addition, the use of integrated design as a non-normative term can form a terminological platform between different disciplines

- Integrated design is a 'means', in relation to a certain 'end'. Therefore, take into account, and present, integrated design in the context of its 'end'. This will also help to define the scale level of the aspired value and the design choices regarding the applied type of integration

- Translate issues of integration from a 'distribution challenge' to a 'design challenge'. This sets the frame for looking conceptually different to issues of integration. In addition, invest in knowledge institutes and projects that pioneer in research and development of new conceptual approaches. These new conceptual approaches will become critical in the development towards a sustainable society

Recommendations for Academics

- The current disciplinary methodological frames and domains are built on extensive research and experience, and have in most cases a long institutional tradition. Integrated design methodology should not be presented as a substituting frame for the disciplinary methodological frames. Inter-, and transdisciplinary domains cannot exist without the current disciplinary domains and should develop in parallel and interrelation with each other. It is therefore recommended to fit education and research programs to this parallel development to obtain mutual benefits. The framework for integrated design as presented in this dissertation can be used as a platform for discussing and developing this interrelation between programs

- Show through the development of new integrated design approaches and methods that many issues of integration are subordinate to design. The conflicting interests in such cases can then be characterized as 'apparent contradictions'. A pioneering example that is already present is 'Building with Nature', which shows that building and nature does not have to conflict, but are subordinate to how these aspects are designed in relation to each other. The development of integrated design methods and approaches can add to the dissolution of such apparent contradictions and places certain aspects in a new context of valuation. The meta-method for integrated design as presented in this dissertation can be used as platform for discussing and developing additional integrated design methods and approaches

- Master education programs should incorporate at least one course that discusses and debates learned disciplinary frames to emphasize the importance of the fact that learned methods are also designed. This will broaden the perspective of students on their own and other domain(s), and possibly prevent them from rigidity or overconfidence within the frame of their own discipline. It also motivates students to further research discussed and debated frames in sequential graduation research. This also adds to personal academic development and science in broad

- Create interdisciplinary education programs to develop transdisciplinary perspectives, terminology, and methods. Also student projects should increasingly be organized as interdisciplinary or interfaculty challenges. The largest potential for innovation is at the interface of different disciplines and in the development of transdisciplinary domains. In addition, it will also prepare students for practical cases in which many disciplines can be involved. Create therefore an academic culture in which interfaculty challenges and transdisciplinary solutions are celebrated. This will possibly lead to more personal initiative, courage, and support regarding integrated design in future professional roles

- Develop the T-shaped professional within the context of integrated design as a specialist in integrated design, instead of a generalist manager that has a certain discipline, but knows 'a little bit of everything'. This dissertation presents 10 principle notes that form 10 aspects in which the T-shaped professional should become a specialist to support the integrated design process. The 10 principle notes can also support defining focus areas for the development and embedment of education programs and research agendas to educate the integrated design professionals of the future

Recommendations for Practitioners

- Define a leading program with dominant forms of aspired value that make a feasible integrated case. This leading program shapes the window of opportunity for additional and/or less dominant forms of aspired value

- Define the scale level and design aspect that forms the motivation for integration in the specific case. This determines the type of integration that is relevant on different scale levels and for different design aspects

- Use integrated design as a strategic instrument in cases of lack of property or stakeholder power to fulfill institutional responsibilities. Integrated design can result in the incorporation of forms of value which would not have been incorporated from a monodisciplinary perspective

- Create buffers to extent momentum. This can from a financial point of view for example be a fund that pre-finances projects at a particular moment in time. Stakeholders that are willing to invest, but lack the means at that particular moment of decision-making, due to for example already labeled budgets for other projects, are in that situation still able to participate. From a governance point of view, buffers can for example be related to special regulations for innovative applications of integration in projects, which makes them less sensitive for governmental shifts or disciplinary defined policies that slow down the decision-making process

- Frame the integrated case in such a way that it becomes eligible for budgets and that it attaches to policies. Because multiple disciplines, institutions, and departments can be involved in the integrated context, the shared responsibility can cause issues and opportunities in relation to budgets and policies. Therefore, the framing of the integrated case is essential to create a feasible case

- Create short-term pilots and testing grounds that are able to develop towards scalable concepts for application at other locations. Couple these pilots therefore also to research to obtain more knowledge about integrated cases. Describe this knowledge, and frame the projects in the governmental domain as pioneering projects that define how we are going to deal with for example interrelated challenges of climate change, housing, mobility, waste, energy transition, and biodiversity. Therefore, a risk-driven approach should be substituted by a concept development approach to create opportunities for trial and error. The short-term pilots should be linked to a long-term approach regarding concept development

- The complexity of integration increases with the amount of stakeholders and corresponding forms of aspired value and design aspects. In addition, forms of aspired value can change over time and are therewith dynamic. The question is if an individual specialist or an expert team in integrated design is able to oversee all the aspects and their dynamic interrelations over time. Although the question is valid if this is not subordinate to deep uncertainty from an absolute point of view, even the definition of interrelations that are in the scope of the designer can become very complex. It is therefore recommended to investigate opportunities to develop tools that are complementary to people's cognitive abilities in this context. The development of complementary artificial intelligent tools to support people's cognitive abilities can possibly add to the development of designs that incorporate more forms of aspired value and their interrelated dynamics over time

References

Ackoff, R.L. (1978). *The Art of Problem Solving. Accompanied by Ackoff's Fables*. New York: John Wiley & Sons.

Ackoff, R.L. (1999). Re-Creating the Corporation: A Design of Organizations for the 21st Century. New York: Oxford University Press.

Alexander, C. (1964). *Notes on the Synthesis of Form*. Cambridge, Massachusetts: Harvard University Press.

Alexander, C. (1971). The State of the Art in Design Methods. *DMG Newsletter*, 5(3): 3-7.

Alexander, C. (1977). *A Pattern Language*. New York: Oxford University Press.

Allport, G.W. (1940). The Psychologist's Frame of Reference. *Psychological Bulletin*, 37: 1-28.

Arcadis (2013a). *Projectplan Kustversterking Katwijk*. Retrieved from https://www.kustwerkkatwijk.nl/media/files/Projectplan%20Kustversterking%20Katwijk.pdf. (Dutch).

Arcadis (2013b). Bovenaanzicht Dijk-in-Duin Katwijk [Ilustration]. In: Arcadis (2013). *Projectplan Kustversterking Katwijk*. Retrieved from https://www.kustwerkkatwijk.nl/media/files/Projectplan%20Kustversterking%20Katwijk.pdf. (Dutch).

Arcadis (2013c). Karakteristieke Technische Doorsnede Dijk [Ilustration]. In: Arcadis (2013). *Projectplan Kustversterking Katwijk*. Retrieved from https://www.kustwerkkatwijk.nl/media/files/Projectplan%20Kustversterking%20Katwijk.pdf. (Dutch).

Archer, L.B. (1965). *Systematic Method for Designers*. London: Design Council.

Archer, L.B. (1979). Design as a Discipline. *Design Studies*, 1(1): 17-20.

Arnold, R.D. & Wade, J.P. (2015). A Definition of Systems Thinking: A Systems Approach. Procedia Computer Science, 44: 669-678.

Arup (n.d.). [Plaszow II Wastewater Treatment Works] [Photograph]. Retrieved from https://www.arup.com/projects/plaszow-ii-wastewater-treatment-works.

Asimov, M. (1962). *Introduction to Design.* Englewood Cliffs: Prentice-Hall.

Badke-Schaub, P., Cardoso, C., Daalhuizen, J., Lauche, K., Jalote-Parmer, A., Neumann, A., Roozenburg, N., Secomandi, F. & da Silva Vieira, S. (2010). Solving an Unresolvable Puzzle? In: Vries, de H.H. & Stappers, P.J. (Eds.), *How to Support the Designer in Context, Design Research in The Netherlands 2010: Proceedings of The Symposium held on May 20-21 2010, Eindhoven University of Technology, Bouwstenen*, 142: 79-90. Eindhoven: Eindhoven University of Technology.

Bayazit, N. (2004). Investigating Design: A Review of Forty Years of Design Research. *Design Issues*, 20(1): 16-29.

Bar-Yam, Y. (2003). *When Systems Engineering Fails - Toward Complex Systems Engineering*, IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC), 2: 2021-2028. Washington DC, US.

Beheshti, M.R. (1999). *Handboek Systematisch Ontwerpen in de Civiele Techniek en Bouwkunde*. Delft: Delft University Press. (Dutch).

Benavides, E.M. (2012). *Advanced Engineering Design: An Integrated Approach*. Cambridge: Woodhead Publishing Limited.

Bertalanffy, von L. (1968). *General Systems Theory*. New York: Braziller.

Biopolus (n.d.). MNR Reactor Array [Illustration]. Retrieved from http://www.biopolus.net/technology/.

Biskjaer, M.M. & Halskov, K. (2013). Decisive Constraints as a Creative Resource in Interaction Design. *Digital Creativity*, 25(1): 27-61.

Blessing, L.T.M. (1994). *A Process-Based Approach to Computer-Supported Engineering Design*. (PhD Thesis). Enschede: Twente University.

Boeijen, van A., Daalhuizen, J., Zijlstra, J. & Schoor, van der R. (2013). *Delft Design Guide: Design Methods Delft University of Technology, Faculty of Industrial Design Engineering*. Amsterdam: BIS Publishers.

Bogue, R. (2007). Design for Disassembly: A Critical Twenty-First Century Discipline. *Assembly Automation*, 27(4): 285-289.

Brenner, W. & Uebernickel, F. (2016). *Design Thinking for Innovation: Research and Practice*. Cham: Springer International Publishing.

Buchanan, R. & Margolin, V. (1995). *Discovering Design: Explorations in Design Studies*. Chicago: The University of Chicago Press.

Buchanan, R. (2001). Design Research and the New Learning. *Design Issues*, 17(4).

Buijs, J. (2003). Modeling Product Innovation Processes, from Linear Logic to Circular Chaos. *Creativity and Innovation Management*, 12(2).

Buijs, J. & Valkenburg, R. (2005). *Integrale Productontwikkeling*. Amsterdam: Boom Lemma Uitgevers. (Dutch).

Carton, L. (2007). *Map Making and Map Use in a Multi-Actor Context*. (PhD Thesis). Delft: JB&A.

Churchman, C.W. (1967). Wicked Problems, *Management Science*, 4(14): B-141-B142.

Cross, N. (1990). The Nature and Nurture of Design Ability, *Design Studies*, 11(3): 127-140.

Cross, N. (1991). *Research in Design Thinking*. Delft: Delft University Press.

Cross, N. (1993). Science and Design Methodology: A Review. *Research in Engineering Design*, 5: 63-69.

Cummings, M.L. (2006). Integrating Ethics in Design Through the Value-Sensitive Design Approach. *Science and Engineering Ethics*, 12(4): 701-715.

DDMLL (2007, October 1). HK Central Pedder Street Crosswalk LV Citibank Bus Taxi [Photograph]. Retrieved from https://nl.m.wikipedia.org/wiki/Bestand:HK_Central_Pedder_Street_Crosswalk_LV_Citibank_Bus_Taxi.JPG.

De Urbanisten (n.d.a). Skaters Waarderen het Activiteiten-Bassin Vanwege de Vrije Vormgeving [Photograph]. In: Rietveld, G. (2014). 's Werelds Eerste Waterplein Officieel een Succes. *Straatbeeld*: 10-15. (Dutch).

De Urbanisten (n.d.b). Het Grote Sportveld Wordt Goed Gebruikt Door de Studenten en de Sportschool [Photograph]. In: Rietveld, G. (2014). 's Werelds Eerste Waterplein Officieel een Succes. *Straatbeeld*: 10-15. (Dutch).

De Urbanisten (n.d.c). [Large Basin Filled With Water] [Photograph]. In: Landscape Record (2016b). Water Sensitivity: To Deal with Stormwater in a Positive Way - An Interview with De Urbanisten. *Landscape Record*, 1(2): 127-128.

De Urbanisten (n.d.d). [Overview Large Basin Filled With Water] [Photograph]. In: Landscape Record (2016b). Water Sensitivity: To Deal with Stormwater in a Positive Way - An Interview with De Urbanisten. *Landscape Record*, 1(2): 127-128.

Dijksterhuis, E.J. (1950). *De Mechanisering van het Wereldbeeld*. Amsterdam: Meulenhoff. (Dutch).

Dorst, C.H. (1997). *Describing Design: A Comparison of Paradigms*. (PhD Thesis). Rotterdam: Vormgeving Rotterdam.

Dorst, C.H. & Cross, N. (2001). Creativity in the Design Process: Co-Evolution of Problem-Solution. *Design Studies*, 22(5): 425-437.

Dorst, C.H. & Vermaas, P.E. (2005). John Gero's Function-Behaviour-Structure Model of Designing: A Critical Analysis. *Research in Engineering Design*, 16: 17-26.

Dorst, C.H. (2011). The Core of Design Thinking and its Application. *Design Studies*, 32: 521-532.

Dorst, C.H. (2015). *Frame Innovation: Create New Thinking by Design*. Cambridge, Massachusetts: The MIT Press.

Eekels, J. (1983). Design Processes Seen as Decision Chains; Their Intuitive and Discursive Aspects. In: Proceedings of the International Conference on Engineering Design - ICED 1983, 3. Heurista, Zürich.

Eekhout, M. (2008). *Methodology for Product Development in Architecture*. Amsterdam: IOS Press.

Ellsberg, D. (1961). Risk, Ambiquity and the Savage Axioms. *Quarterly Journal of Economics*, 75: 643-669.

Elster, J. (2000). *Ulysses Unbound*. New York: Cambridge University Press.

Eppinger, S.D. & Browning, T.R. (2012). *Design Structure Matrix Methods and Applications*. Cambridge, Massachusetts: The MIT Press.

Fernandes, M.T. (2012). A Holistic and Cultural view of Value. *Advances in Management & Applied Economics*, 2(1): 55-107.

Frei, R. & Di Marzo Serugendo, G. (2011). Concepts in Complexity Engineering. *International Journal of Bio-Inspired Computation*, 3(2).

Friedman, B. (1996). Value-Sensitive Design. *Interactions November + December*: 17-23.

Friedman, B., Kahn, Jr. P.H. & Borning, A. (2006). Value Sensitive Design and Information Systems. In: Himma, K.E. & Tavani, H.T. (Eds.), *The Handbook of Information and Computer Ethics* (pp. 69-101). New York: John Wiley & Sons.

Fuller, R.B. (1965). Conceptuality of Fundamental Structures. In: *Structure in Art and in Science, 66, ed. Kepes, G., (1965).* New York: George Braziller.

Gamson, W. & Ryan, C. (2005). Thinking about Elephants. Toward a Dialogue with George Lakoff. *The Public Eye Magazine*.

Gero, J.S. (1990). Design Prototypes: A Knowledge Representation Schema for Design. *AI Magazine*, 11(4): 26-36.

Gero, J.S. & Kannengiesser, U. (2007). A Function-Behavior-Structure Ontology of Processes. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 21: 379-391.

Gershenson, C. (2007). *Design and Control of Self-Organizing Systems*. (PhD Thesis). Printed by: CopIt ArXives.

Gielingh, W. (2008). A Theory for the Modeling of Complex and Dynamic Systems. *ITcon*, 13.

Golden, B. (2013). *A Unified Formalism for Complex Systems Architecture*. (PhD Thesis). Department of Computer Science, École Polytechnique.

Greenfield, A. (2006). *Everyware: The Dawning Age of Ubiquitous Computing*. San Francisco: Peachpit.

Gropius, W. (1962). 'Is There a Science of Design?'. *Magazine of Art* (Dec. 1947) reprinted in: *Scope of Total Architecture*. New York: Collier Books.

Gulledge, T. (2006). 'What is Integration?'. *Industrial Management & Data Systems*, 106(1): 5-20.

Habermas, J. (1968). *Erkenntnis und Interesse*. Frankfurt am Main: Suhrkamp. (English translation: Habermas, J. (1978). Knowledge and Human Interests, (2nd edition). London: Heinemann).

Heeling, J., Meyer, V.J. & Westrik, J. (2002). *De Kern van de Stedebouw in het Perspectief van de 21ste Eeuw. Deel 1: Het Ontwerp van de Stadsplattegrond*. Amsterdam: SUN Publishers. (Dutch).

Hekkert, P.P.M. & van Dijk, M.B. (2011). *Vision in Design: A Guidebook for Innovators*. Amsterdam: BIS Publishers.

Hertogh, M.J.C.M. & Westerveld, E. (2010). *Playing with Complexity*. Amsterdam: Thieme.

Hertogh, M.J.C.M. (2013, September 6). *Connect and Renew*. (Inaugural Speech). Retrieved from http://resolver.tudelft.nl/uuid:8e012378-6db1-43bd-a0ef-2d48dd02d295.

Heskett, J. (2005). *Design: A Very Short Introduction*. Oxford: Oxford University Press.

Hevner, A.R., et al. (2004). Design Science in Information Systems Research, *MIS Quarterly,* 28(1): 75-105.

Heylighen, F. (1989). Causality as Distinction Conservation: A Theory of Predictability, Reversibility and Time Order. *Cybernetics and Systems*, 20: 361-384.

Heylighen, F. (1990a). Classical and Non-Classical Representations in Physics I. *Cybernetics and Systems*, 21: 423-444.

Heylighen, F. (1990b). *Representation and Change. A Metarepresentational Framework for the Foundations of Physical and Cognitive Science*. Gent: Communication and Cognition.

Hindustan Times (n.d.). [Traffic Jam at Road Crossing] [Photograph]. Retrieved from https://shefaly-yogendra.com/blog/2015/05/16/the-design-challenge-called-indian-traffic-1/.

Hodgson, G.M. (2006). What are Institutions? *Journal of Economic Issues*, 40(1): 1-25.

Höltta-Otto, K. & Weck, de O. (2007). Degree of Modularity in Engineering Systems and Products with Technical and Business Constraints. *Concurrent Engineering: Research and Applications*, 15(2): 113-126.

Hoog, de M., Sijmons, D. & Verschuuren, S. (1998). Herontwerp van het Laagland. In: Frieling, D.H. (Ed.), *Het Metropolitane Debat* (pp. 74-87). Bussum: Thoth. (Dutch).

Hoven, van den J., Lokhorst, G.J. & Poel, van de I. (2012). Engineering and the Problem of Moral Overload. *Science and Engineering Ethics*, 18: 143-155.

Hoven, van den J., Vermaas, P.E. & Poel, van de I. (2015). Design for Values: An Introduction. In: Hoven, van den J., Vermaas, P.E. & Poel, van de I. (Eds.), *Handbook of Ethics, Values, and Technological Design* (pp. 1-7). Dordrecht: Springer.

Johnston, P. (2017). The Aero-Engine Business Model: Rolls-Royce's Perspective. In: Richter, K. & Walther, J. (Eds.), *Supply Chain Integration Challenges in Commercial Aerospace* (pp. 237-248). Cham: Springer International Publishing.

Jones, J.C. & Thornley, D. (1963). *A Method of Systematic Design*. Conference on Design Methods. Oxford: Pergamon.

Jones, J.C. (1966). Design methods compared 1: Strategies. *Design*, 212: 32-35.

Jones, J.C. (1970). An Experiment in Education for Planning and Design. *Emerging Methods in Environmental Design and Planning*: 353-357.

Jones, J.C. (1977). How My Thoughts About Design Methods Have Changed During the Years. *Design Methods and Theories*, 11(1): 48-62.

Jones, J.C. (1992). *Design Methods*. (2nd edition). New York: John Wiley & Sons.

Jong, de T.M. (1992). *Kleine Methodologie voor Ontwerpend Onderzoek*. Amsterdam: Boom Uitgevers. (Dutch).

Jost, J. (2004). External and Internal Complexity of Complex Adaptive Systems. *Theory in Biosciences*, 123(1): 69-88.

Kahn, R.L. & Prager, D.J. (1994). Interdisciplinary Collaborations are a Scientific and Social Imperative. *The Scientist*, 17: 11-12.

Kahnemann, D. & Tversky, A. (1979). Prospect Theory: An Analysis of Decision Under Risk. *Econometrica*, 47(2): 263-291.

Karstens, S. (2009). *Bridging Boundaries: Making Scale Choices in Multi-Actor Policy Analysis on Water Management*. (PhD Thesis). Amsterdam: IOS Press.

Keates, S. & Clarkson, J. (2003). Countering Design Exclusion. In: Clarkson, J., Coleman, R., Keates, S. & Lebbon, C. (Eds.), *Inclusive Design: Design for the Whole Population* (pp. 438-453). London: Springer-Verlag.

Kicinger, R., Arciszewski, T. & De Jong, K. (2005). Emergent Designer: An Integrated Research and Design Support Tool Based on Models of Complex Systems. *ITcon*, 10: 329-347.

Kingdon, J.W. (1995). *Agendas, Alternatives, and Public Policies*. (2nd edition). New York: Longman.

Kleinsmann, M., Buijs, J. & Valkenburg, R. (2010). Understanding the Complexity of Knowledge Integration in Collaborative New Product Development Teams: A Case Study. *Journal of Engineering and Technology Management*, 27: 20-32.

Koestler, A. (1964). *The Act of Creation*. London: Hutchinson.

Kraft, M.E. & Clary, B.B. (1991). Citizen Participation and the NIMBY Syndrome: Public Response to Radioactive Waste Disposal. *Political Research Quarterly*, 44(2): 299-328.

Kroonenberg, H.H. & Siers, F.J. (1992). *Methodisch Ontwerpen*. Groningen: Noordhoff Uitgervers. (Dutch).

Kuhn, T.S. (1962). *The Structure of Scientific Revolutions*. (2nd rev. ed.). 1970. Chicago: University of Chicago Press.

Lakoff, G. & Ferguson, S. (2006). Crucial Issues not Addressed in the Immigration Debate: Why Deep Framing Matters. University of California. Berkeley, California.

Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.a). Overview at Night [Photograph]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.b). Basin 1 is Mainly Used by Skaters [Photograph]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.c). [Overview of Different Catchment Areas per Basin] [Illustration]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.d). The 'Water Wall' Guiding the Rain From a Wider Surrounding Into the Central Basin During a Cloudburst Situation [Photograph]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.e). The 'Rain Well' Guiding Rain Water From the Roof Onto the Square [Photograph]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.f). Stainless Steel Gutters Guiding the Rain Water [Photograph]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Landscape Record (n.d.g). Special Water Feature [Photograph]. In: Landscape Record (2016a). Water Square Benthemplein. *Landscape Record*, 1(2): 90-99.

Lawson, B. (2005). *How Designers Think: The Design Process Demystified. (4th ed.)*. New York: Routledge.

Lawson, B., & Dorst K. (2009). *Design Expertise*. Oxford: Architectural Press.

Leupen, B., Grafe, C., Körnig, N., Lampe, M. & Zeeuw, de P. (2013). *Ontwerp en Analyse*. Rotterdam: Nai010 Publishers. (Dutch).

Love, T. (2002). Constructing a Coherent Cross-Disciplinary Body of Theory about Designing and Designs: Some Philosophical Issues. *Design Studies,* 23: 345-361.

Luckman, J. (1967). An Approach to the Management of Design. *Operational Research Quarterly*, 18(4).

Maher, M.L., Poon, J. & Boulanger, S. (1996). Formalising Design Exploration as Co-Evolution: A Combined Gene Approach. In: Gero, J.S. (Ed.), *Advances in Formal Design Methods for CAD*: 3-33. London: Chapman & Hall.

Maier, M.W. & Rechtin, E. (2000). *The Art of Systems Architecting*, (2nd ed.). Baco Raton: CRC Press.

Maier, J.R.A. & Fadel, G.M. (2006). Understanding the Complexity of Design. In: Braha, D., Minai, A.A. & Bar-Yam, Y. (Eds.), *Complex Engineering Systems. Science Meets Technology* (pp. 122-140). New York: Springer.

Manders-Huits, N. (2011). What Values in Design? The Challenge of Incorporating Moral Values into Design. *Science and Engineering Ethics*, 17: 271-287.

Mang, P. & Reed, B. (2012). Designing From Place: A Regenerative Framework and Methodology. *Building Research and Information*, 40(1): 23-38.

March, L.J. (1976). The Logic of Design and the Question of Value. In: March, L.J. (Ed.), *The Architecture of Form*. Cambridge: Cambridge University Press.

Markowitz, H. (1952). The Utility of Wealth. *The Journal of Political Economy*, 60(2): 151-158.

Matchett, E. (1968). *Fundamental Design Method*. Birmingham: FDM Publishing Limited.

Mau, B. (2007). *Massive Change*. London: Phaidon Press.

Mavris, D.N. & Pinon, O.J. (2011). An Overview of Design Challenges and Methods in Aerospace Engineering. In: Hammami, O., Krob, D. & Voirin, J.L. (Eds.), *Complex Systems Design and Management*. New York: Springer International Publishing.

McDonough, W. & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way we Make Things*. New York: North Point Press.

McGregor, S.L.T. (2015). Transdisciplinary Knowledge Creation. In: Gibbs, P. (Ed.), *Transdisciplinary Professional Learning and Practice* (pp. 9-24). Cham: Springer International Publishing.

Monastersky, R. (2015). *The Human Age*. London: Macmillan Publishers.

Monat, J.P. & Gannon, T.F. (2015). What is Systems Thinking? A Review of Selected Literature Plus Recommendations. *American Journal of Systems Science*, 4(1): 11-26.

Mossop, E. (2006). Landscapes of Infrastructure. In: Waldheim, C.I. (Ed.), *The Landscape Urbanism Reader* (pp. 163-177). New York: Princeton Architectural Press.

Nelson, H. & Stolterman, E. (2002). *The Design Way - Intentional Change in an Unpredictable World*. New Jersey: Educational Technology Publications.

Neuhauser, L. & Pohl, C. (2015). Integrating Transdisciplinarity and Translational Concepts and Methods into Graduate Education. In: Gibbs, P. (Ed.), *Transdisciplinary Professional Learning and Practice* (pp. 99-120). Cham: Springer International Publishing.

Nevejan, C. & Bazier, F. (2015). Design for the Value of Presence. In: Hoven, van den J., Vermaas, P.E. & Poel, van de I. (Eds.), *Handbook of Ethics, Values, and Technological Design* (pp. 403-430). Dordrecht: Springer.

Nijhuis, S. & Jauslin, D. (2015). Urban Landscape Infrastructures. In: Nijhuis, S., Jauslin, D. & Hoeven, van der F. (Eds.), *Flowscapes: Designing Infrastructure as Landscapes* (pp. 13-34). Delft: Delft University Press.

Norman, D.A. & Stappers, P.J. (2015). DesignX: Complex Sociotechnical Systems. *She Ji: The Journal of Design, Economics, and Innovation*, 1(2): 83-106.

North, D.C. (1994). Economic Performance Through Time. *American Economic Review*, 84(3): 359-367.

Null, R. (2014). *Universal Design: Principles and Models*. Baco Raton: CRC Press.

Ohio State University (n.d.) Paths With Purpose [Photograph]. Retrieved from https://www.osu.edu/paths-with-purpose/images/carousel/oval.jpg.

Oosterlaken, I. (2015a). Human Capabilities in Design for Values. In: Hoven, van den J., Vermaas, P.E. & Poel, van de I. (dds.), *Handbook of Ethics, Values, and Technological Design* (pp. 221-250). Dordrecht: Springer.

Oosterlaken, I. (2015b). Applying Value Sensitive Design (VSD) to Wind Turbines and Wind Parks: An Exploration. Science and Engineering Ethics, 21: 359-379.

Organica Water (2015a, October 7). Why We Placed a Wastewater Treatment Plant in the Middle of Jakarta. Retrieved from https://www.organicawater.com/why-we-placed-a-wastewater-treatment-plant-in-the-middle-of-jakarta-bp/.

Organica Water (2015b, October 7). Organica-Powered Wastewater Treatment Plant in Jakarta, Indonesia [Illustration]. In: Organica Water (2015a, October 7). Why We Placed a Wastewater Treatment Plant in the Middle of Jakarta. Retrieved from https://www.organicawater.com/why-we-placed-a-wastewater-treatment-plant-in-the-middle-of-jakarta-bp/.

Organica Water (n.d.). [Organica Food Chain Reactor (FCR)] [Illustration]. Retrieved from https://www.organicawater.com/facility.

[Overview Situation Katwijk] (n.d.). [Illustration]. In: Kustwerk Katwijk (2015). *Kustwerk Katwijk*. Zutphen: Drukkerij Tesink. (Dutch).

Page, J.K. (1966). *Contribution to Building for People*, 1965 Conference Report. London: Ministry of Public Buildings and Works.

Pahl, G. & Beitz, W. (1984). *Engineering Design*. London: Design Council.

Papanek, V. (1971). *Design for the real world; human ecology and social change*. New York: Pantheon Books.

Paton, B. & Dorst, K. (2011). Briefing and Reframing: A Situated Practice. *Design Studies*, 32: 573-587.

Peirce, C.S. (1992a). In: Ketner, K.L. (Ed.), *Reasoning and the Logic of Things: The Cambridge Conferences Lectures of 1898*. Cambridge: Harvard University Press.

Peirce, C.S. (1992b). In: Houser, N. & Kloesel, C. (Eds.), *The Essential Peirce, 1(1867-1893)*. Bloomington: Indiana University Press.

Peirce, C.S. (1998). In: Houser, N. & Kloesel, C. (Eds.), *The Essential Peirce, 2(1893-1913)*. Bloomington: Indiana University Press.

Persson, H., Åhman, H., Yngling, A.A. & Gulliksen, J. (2014). Universal Design, Inclusive Design, Accessible Design, Design for All: Different Concepts—One Goal? On the Concept of Accessibility - Historical, Methodological and Philosophical Aspects. *Universal Access in the Information Societ*y, 14(4): 505-526.

Pimmler, T.U. & Eppinger, S.D. (1994). *Integration Analysis of Product Decompositions*. ASME Design Theory and Methodology Conference Minneapolis, September, 1994.

Poel, van de I., & Royakkers, L. (2011). *Ethics, Technology and Engineering: An Introduction*. Oxford: Wiley-Blackwell.

Poel, van de I. (2013). Translating Values into Design Requirements. In: Mitchfelder, D., McCarty, N. & Goldberg, D.E. (Eds.), *Philosophy and Engineering: Reflections on Practice, Principles and Process* (pp. 253-266). Dordrecht: Springer.

Poel, van de I. (2015). Conflicting Values in Design for Values. In: Hoven, van den J., Vermaas, P.E. & Poel, van de I. (Eds.), *Handbook of Ethics, Values, and Technological Design* (pp. 89-116). Dordrecht: Springer.

Pollak, L. (2006). Constructed Ground: Questions of Scale. In: Waldheim, C.I. (Ed.), *The Landscape Urbanism Reader* (pp. 125-139). New York: Princeton Architectural Press.

Pourdehnad, J., Wexler, E.R. & Wilson, D.V. (2011). Integrating Systems Thinking and Design Thinking. *Systems Thinker*, 22(9).

Pugh, S. (1991). *Total Design: Integrated Methods for Successful Product Engineering*. Boston, MA: Addison-Wesley Publishers.

Puts, H. & Heijden, van der J. (2017a). Toekomstwaarde als Basis voor Meervoudige Investeringen. In: Bouma, G. (Ed.), *Gedeelde Ruimte, Bijdragen aan Plandag 2017* (pp. 187-196). Antwerpen: Stichting Planologische Discussiedagen.

Puts, H. & Heijden, van der J. (2017b). De Potentiële 'Toekomstwaardetrap' van Gouda [Illustration]. In: Puts, H. & Heijden, van der J. (2017a). Toekomstwaarde als Basis voor Meervoudige Investeringen. In: Bouma, G. (Ed.), *Gedeelde Ruimte, Bijdragen aan Plandag 2017* (pp. 187-196). Antwerpen: Stichting Planologische Discussiedagen.

Ralph, P. & Wand, Y. (2009). A Proposal for the Formal Definition of the Design Concept. In: Lyytinen, K., Loucopoulos, P., Mylopoulos, J. & Robinson, B. (Eds.), *Design Requirements Engineering: A Ten-Year Perspective, Lecture Notes in Business Information Processing*, 14: 103-136. Berlin: Springer.

Rand, P. (2001). *A Designer's Art*. New Haven: Yale University Press.

Reed, B. (2007). Shifting From 'Sustainability' to Regeneration. *Building Research & Information*, 35(6): 674-680.

Reswick, J.B. (1965). *Prospectus for the Engineering Design Center*. Cleveland, Ohio: Case Institute of Technology.

Richardson, J. (1984). *Basic Design*. New Jersey: Prentice-Hall.

Rietveld, G. (2014). 's Werelds Eerste Waterplein Officieel een Succes. *Straatbeeld*: 10-15. (Dutch).

Rijkswaterstaat (2016). *The Sand Motor: Driver of Innovative Coast Maintenance*. Utrecht: Rijkswaterstaat.

Rios, F.C., Chong, W.K. & Grau, D. (2015). Design for Disassembly and Deconstruction - Challenges and Opportunities. *Procedia Engineering*, 118: 1296-1304.

Rittel, H. (1973). The State of the Art in Design Methods. *Design Methods and Theories*, 7(2): 143-147.

Rittel, H., & Webber, M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, 4: 155-169.

Roland, E.C. & Landua, G. (2013). *Regenerative Enterprise. Optimizing for Multi-Capital Abundance*. Boston: Shambala Publications.

Roozenburg, N.F.M. & Cross, N. (1991). Models of the Design Process: Integrating Across the Disciplines. *Design Studies*, 12(4): 215-220.

Roozenburg, N.F.M. (1993). On the Pattern of Reasoning in Innovative Design. *Design Studies*, 14(1): 4-18.

Roozenburg, N.F.M. & Eekels, J. (1995). *Product Design, Fundamentals and Methods*. Chichester: John Wiley & Sons.

Roser, M., Ritchie, H. & Ortiz-Espina, E. (2013). The Size of the World Population over the Last 12.000 Years [Chart]. Retrieved from: https://ourworldindata.org/world-population-growth.

Rowe, P.G. (1987). *Design Thinking*. Cambridge, Massachusetts: The MIT Press.

Royal HaskoningDHV (2017a). Take Back Chemicals. Retrieved from https://www.royalhaskoningdhv.com/en-gb/services/a-z-services/take-back-chemicals/1215.

Royal HaskoningDHV (2017b). [Relation Between Incentives of Manufacturer and User for a Traditional Business Model and Take Back Chemicals Model] [Illustration]. In: Royal HaskoningDHV (2017a). Take Back Chemicals. Retrieved from https://www.royalhaskoningdhv.com/en-gb/services/a-z-services/take-back-chemicals/1215.

Savransky, S.D. (2000). *Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving*. Baco Raton: CRC Press.

Schaick, van J. (2005). Integrating the Social and Spatial Aspects of the Urban System. In Hulsbergen, E.D., Klaasen, I.T. & Kriens, I. (Eds.), *Shifting Sense - Looking Back to the Future in Spatial Planning* (pp. 251-264). Amsterdam: Techne Press.

Schaick, van J. & Klaasen, I.T. (2011). The Dutch Layers Approach to Spatial Planning and Design: A Fruitful Planning Tool or a Temporary Phenomenon? *European Planning Studies*, 19(10): 1775-1796.

Schön, D.A. (1983). *The Reflective Practitioner, How Professionals Think in Action*. New York: Basic Books.

Schön, D.A. (1987). *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*. San Francisco: Jossey-Bass Publishers.

Shannon, K. & Smets, M. (2010). *The Landscape of Contemporary Infrastructure*. Rotterdam: Nai010 Publishers.

Simon, H.A. (1969). *The Sciences of the Artificial*. Cambridge, Massachusetts: The MIT Press.

Sosa, M.E., Eppinger, S.D. & Rowles, C.M. (2003). Identifying Modular and Integrative Systems and Their Impact on Design Team Interactions. *Journal of Mechanical Design*, 125: 240-252.

Stacey, M. & Eckert, C. (2010). Reshaping the Box: Creative Designing as Constraints Management. *International Journal of Product Development*, 11(3/4): 241-255.

Stock, P. & Burton, J.F. (2011). Defining Terms for Integrated (Multi-Inter-Trans-Disciplinary) Sustainability Research. *Sustainability*, 3: 1090-1113.

Stokes, P.D. (2006). *Creativity From Constraints: The Psychology of Breakthrough*. New York: Springer Publishing Company.

Suckle, A. (1980). *By Their Own Design*. New York: Whitney Library of Design.

Suh, N.P. (1990). *The Principles of Design*. New York: Oxford University Press.

Suh, N. P. (2001). *Axiomatic Design*. New York: Oxford University Press.

Susskind, L. & Field, P. (1996). *Dealing With An Angry Public. The Mutual Gains Approach to Resolving Disputes*. New York: The Free Press.

Taura, T. & Nagai, Y. (2013). *Concept Generation for Design Creativity*. London: Springer-Verlag.

Tectobio (n.d.). Visual Concept of Strijp-S Biomakery at day and night [Illustration]. Retrieved from http://www.biopolus.net/project/strijp-s-eindhoven-the-netherlands/.

[The Parking Garage Under Construction] (n.d.). [Photograph]. In: Kustwerk Katwijk (2015). *Kustwerk Katwijk*. Zutphen: Drukkerij Tesink. (Dutch).

Tittensor, D.P., Walpole, M., Hill, S.L.L., Boyce, D.G., Britten, G.L., Burgess, N.D., Butchart, S.H.M., Leadley, P.W., Regan, E.C., Alkemade, R. et al. (2014). A Mid-Term Analysis of Progress Toward International Biodiversity Targets. *Science,* 346(6206): 241-244.

Tzonis, A. (1992). Huts, Ships and Bottleracks: Design by Analogy for Architects and/or Machines. In Cross, N., Dorst, C.H. & Roozenburg, N. (Eds.), *Research in Design Thinking* (pp. 139-164). Delft: Delft University Press.

Ulrich, K.T. (1995). The Role of Product Architecture in the Manufacturing Firm. *Research Policy*, 24: 419-440.

Ulrich, K.T. & Eppinger, S.D. (2016). *Product Design and Development (6th ed.)*. New York: McGraw-Hill.

United Nations (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables*. Working Paper No. ESA/P/WP/248.

United Nations (2018). *The Sustainable Development Goals Report 2018*. Retrieved from https://unstats.un.org/sdgs/files/report/2018/TheSustainableDevelopmentGoalsReport2018-EN.pdf.

Valkenburg, R. & Dorst, C.H. (1998). The Reflective Practice of Design Teams. *Design Studies*, 19(3): 249-271.

Visser, J.L. (2019, July, 2). Entrances and Exits of the Parking Garage Parallel to the Boulevard and Driveway Positioned Between Houses [Photograph]. (Author).

Voorendt, M.Z. (2017). *Design Principles of Multifunctional Flood Defences*. Enschede: Ipskamp Printing.

Vos, R., Melkert, J.A. & Zandbergen, B.T.C. (2016, May 18). Designing Aircraft in 7 Lectures [Powerpoint]. Retrieved from Delft University of Technology. Course: Aerospace Design and Systems Engineering Elements I.

Vriend, de H.J. & Koningsveld, van M. (2012). *Building With Nature: Thinking, Acting, and Interacting Differently*. Dordrecht: Ecoshape.

Vriend, de H.J., Koningsveld, van M., Aarninkhof, S.G.J., Vries, de M.B. & Baptist, M.J. (2015). Sustainable Hydraulic Engineering Through Building With Nature. *Journal of Hydro-Environment Research*, 9: 159-171.

Vries, de M.J., Cross, N. & Grant, D.P. (1993). *Design Methodology and Relationships with Science*. Dordrecht: Kluwer Academic Publishers.

Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Gatuszka, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M. et al. (2016). The Anthropocene is Functionally and Stratigraphically Distinct from the Holocene. *Science*, 351(6269): aad2622-1-aad2622-10.

Weick, K.E. (1976). Educational Organizations as Loosely Coupled Systems. *Administrative Science Quarterly*, 21(1): 1-19.

Winkler, T. & Spiekermann, S. (2018). Twenty Years of Value Sensitive Design: A Review of Methodological Practices in VSD Projects. *Ethics and Information Technology*: 1-5.

Wolsink, M. (2000). Wind Power and the NIMBY-Myth: Institutional Capacity and the Limited Significance of Public Support. *Renewable Energy*, 21: 49-64.

World Wildlife Fund (2016). *Living Planet Report 2016: Risk and Resilience in a New Era*. Gland: WWF International.

World Wildlife Fund (2018). *Living Planet Report 2018: Aiming Higher*. Gland: WWF International.

Zeiler, W. & Quanjel, E.M.C.J. (2008). Flexible Sustainable Process Innovation: Integral Building Design Methodology. In: Marjanovic, D., Storga, M., Pavkovic, N. & Bojcetic, N. (Eds.). *Proceedings of the 10th International Design Conference*, 1: 553-560.

Zeng, Y. & Cheng, G.D. (1991). On the Logic of Design. *Design Studies*, 12(3).

Zimmerman, J. & Forlizzi, J. (2008). *Artifact*, 2(1): 41-45.

Appendix A: Overview of Design Process Model and Design Methods per Investigated Faculty

A.1 Aerospace Engineering

Faculty TU Delft	Dominant design process model	Process phases		Design methods	Results	
		Main phases	Sub phases		Output	Additional notes
Aerospace Engineering	Pahl & Beitz (1984)	Analysis	Analysis of customer needs	Market research		
			Translating demands into functional requirements, design parameters and process variables	Axiomatic Design Matrices	Functional requirements, design parameters and process variables	
		Conceptual design	With the analysis and input of requirements, conceptual designs and assessment of designs are developed	Function block schemes	Concept designs which are assessed and optimized in direct feedback loops	
				Multiple Attribute Decision-Making (MADM)		
				Multidisciplinary Analysis and Design Optimization (MDA/MDO)		
				Response Surface Method		
				Artificial Neural Networks		
				Kriging		
				Inductive Learning		
				Parametric Design Formulation		
		Preliminary design	Iterative improvement and selection of design solution	Reduced-Order Model	Further specification and detailing of concept design for full-scale development	
		Detailed design	Detailed specification of final design	Computer-Aided Design (CAD)	Detailed design and fabrication of first product	
				Computer-Aided Manufacturing (CAM)		

A.2 Architecture and the Built Environment

Faculty TU Delft	Dominant design process model	Process phases	Methodological elements applied at faculty		Results	
			Main elements	Differentiation	Output	Additional notes
Architecture & the Built Environment	Schön (1983)	Naming	Context	Plan of requirements	Text, drawings, and models to describe the context	The definition of the context is also strongly influenced by cultural or conventional rules
				Location Analysis		
				Historical Analysis		
				Plan analysis		
				Sketching and modeling		
		Framing	Typology	Associative Method	Associative patterns for design	Expression of associative patterns from typologies in gradual scale 'concept - type - design', and typological scale levels or layers
				Library		
				Sketching and modeling		
			Interpretation	Sketching and modeling	Frame for ordering and composition	Strong emphasize on the introspective element in the design process
		Moving	Ordering and Composition	Graphical conceptual expressions	Preliminary design solutions	Strong emphasize on the introspective element in the design process
				Sketching and modeling		
				Graphical expressions, drawings, movies, photographs		
				Physical scale model (maquette)		
				Sketching and modeling		
		Evaluating	Reflection	Testing	Selection of design solutions and reframing of design challenge	Short feedback loops from the results of experimentation to reframe the design space
				Making		
				Using		
				Sketching and modeling		

A.3 Civil Engineering and Geosciences

Faculty TU Delft	Dominant design process model	Process phases		Design methods	Results	
		Main phases	Sub phases		Output	Additional notes
Civil Engineering & Geosciences	Roozenburg & Eekels (1995)	Analysis	Analysis of the problem	Screen Analysis	Set of requirements and conditions	
				Potential Surface Analysis		
				Process Analysis		
				Function Analysis		
				Stakeholder Analysis		
		Synthesis	Design solutions are developed from abstract to detailed	Combinative Method	Preliminary design solutions	
				Morphological Method		
				AIDA-Method		
				Coding Method		
				Brainstorming		
				Design and Decision-Making Tree		
		Simulation	Operational testing (verification) regarding probabilistic conditions	Reasoning	Operational characteristics of preliminary design solutions	
				Qualitative Modeling		
				Quantitative Modeling		
		Evaluation	Evaluation of preliminary designs regarding requirements (validation)	Qualitative Permutation Method	Evaluation scores of preliminary design solutions	Long iterative loops between decision-making and analysis and synthesis

A.4 Industrial Design

Faculty TU Delft	Dominant design process model	Process phases		Design methods	Results	
		Main phases	Sub phases		Output	Additional notes
Industrial Design	Roozenburg & Eekels (1995)	Analysis	Discover insights for designing	Context Mapping	Insights and understanding for designing	The methods to discover insights for designing can be used during all phases and are not bounded to the sequential stepwise phases
				Cultural Probes		
				User Observations		
				Interviews		
				Questionnaires		
				Focus Group		
				Customer Journey		
				Mind Map		
				Strategy Wheel		
				Trend Analysis		
				Function Analysis		
				Eco Design Strategy Wheel		
				Eco Design Checklist		
				Process Tree		
				Fast Track Life Cycle Analysis		
				Human Power		
				SWOT Analysis		
				Search Areas		
				Ansoff Growth Matrix		
				Miles & Snow Business Strategies		
				Porter Competitive Strategies		
				VRIO Analysis		
				Porter Five Forces		
				Perceptual Map		
				Value Curve		
			Analysis of the problem or challenge	Collage	Definition of the problem or challenge for designing	
				Personas		
				Storyboard		
				Written Scenario		
				Problem Definition		
				List of Requirements		
				Business Model Canvas		
				Marketing Mix or 4Ps		

		Synthesis	Development of ideas and concepts while designing	Fish Trap Model	Preliminary design concepts for selection	
				Morphological Method		
				Synectics		
				Analogies and metaphors		
				Brainstorming		
				Brain Writing & Drawing		
				SCAMPER		
				WWWWWH		
				How-To's		
		Simulation	Operational testing (verification)	Role-Playing	Operational characteristics of preliminary design solutions	
				Design Drawing		
				Technical Documentation (TecDoc)		
				Three-Dimensional Models		
				Video Visualisation		
		Evaluation	Evaluation of preliminary designs regarding requirements (validation)	Interaction Prototyping & Evaluation	Selection of design solution	
				Product Usability Evaluation		
				Product Concept Evaluation		
				Emotion Measurement Instrument (PreMo)		
				Harris Profile		
				EVR Decision Matrix		
				C-Box		
				Itemised Response & PMI		
				Datum Method		
				vALUe		
				Weighted Objectives Method		
				Cost Price Estimation		
			Materials and geometry	Quantitative modeling		
				Visual Methods		
			Connections subsystems/ components	Visual Methods		
			Optimization of form (industrial designer)	Visual Methods		
			Preparation of operational documents	Construction Dossier		

A.5 Mechanical Engineering

Faculty TU Delft	Dominant design process model	Process phases		Design methods	Results	
		Main phases	Sub phases		Output	Additional notes
Mechanical Engineering	Kroonenberg & Siers (1992)	Problem definition	Analysis of the problem (ergonomics, system, manufacturing, etc.) from a functional point of view	Sketching	List of requirements, conditions and main functions	Focus on functionality and safety. CE-norms are European norms and creates the opportunity to trade and legitimate system and system operations
				Reasoning		
				Interviews		
			Decomposition of functions and processes in subsystems	Function block schemes		
				Process-Function Matrix		
				Methodological-Systematics Chart (design blocks)		
			Abstract overview of related functions	Visual expressions of related function blocks		
		Working principle	Morphological overview of potential combinations of solutions	Morphological Chart	Concept design	Direct feedback loops from active sub phases to the problem definition, iterative revisions on scale of main phases. The morphological chart related sub functions to sub solution systems, reductionist and modular method
				Brainstorming		
				Brainwriting		
				Synectics		
				Iterative Method		
				Analogies		
			Assessment and selection of technical and economical aspects of concept solutions/ combinations of subsystems to fulfill the main function	Kesselring Method		
				Weight Matrices		
		Specific design	Risk assessment of preliminary design	Risk Methods	Construction dossier of final design for fabrication prototype and testing	Direct feedback loops from decision-making sub phases to problem definition or preliminary design, iterative revisions on scale of main phases
			Materials and geometry	Quantitative modeling		
				Visual Methods		
			Connections subsystems/ components	Visual Methods		
			Optimization of form (industrial designer)	Visual Methods		
			Preparation of operational documents	Construction Dossier		

Appendix B: Interviewees Project Roles

Interviewee (case number.interviewee number) = interviewee (c.i)

Case (1) Coast Katwijk

Interviewee (1.1)	Project Manager Parking Garage Katwijk, Royal HaskoningDHV
Interviewee (1.2)	Architect Parking Garage Katwijk, Royal HaskoningDHV
Interviewee (1.3)	Landscape Architect, OKRA
Interviewee (1.4)	Project Leader Parking Garage Katwijk, Municipality of Katwijk
Interviewee (1.5)	Project Leader Coast Katwijk, Regional Water Authority Rijnland

Case (2) Benthemplein

Interviewee (2.1)	Project Manager Benthemplein, Municipality of Rotterdam
Interviewee (2.2)	Principal Investigator, Regional Water Authority Schieland and the Krimpenerwaard
Interviewee (2.3)	Asset Manager Surface Water, Municipality of Rotterdam

Case (3) Biomakery Strijp-S

Interviewee (3.1)	Project Leader Biomakery Strijp-S, Regional Water Authority De Dommel
Interviewee (3.2)	Strategic Manager Industry/ Initiator Biomakery Strijp-S, Regional Water Authority De Dommel
Interviewee (3.3)	Director Park Strijp Beheer
Interviewee (3.4)	Strategic Advisor Biomakery Strijp-S, Astrix Consult
Interviewee (3.5)	Program Manager Water, Municipality of Eindhoven

Appendix C: Coding Schemes Cases

C.1 Coast Katwijk

Case: Coast Katwijk				
Topic: Motivation for integration				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
The motivation for integration is driven by availabilities and experiences in former projects	The available context creates opportunities for integration	Opportunities	Available resources	(1.1)(1.2)(1.5)
			Available construction equipment	(1.1)(1.5)
			Chronological benefit	(1.4)
			Other	
	The lack of space and the experience of conflict in former projects drives the desire for integration	Conflicts	Space conflicts	(1.1)(1.4)
			Conflicting interests	(1.1)(1.4)
			Interference of systems	(1.1)(1.4)
			Insurance issues	(1.1)
			Experience of conflict in former projects	(1.4)
			Conflicting norms	(1.4)
			Other	
Topic: Design aspects in relation to integration				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
The aspired integration is context dependent	The aspired value can be defined on different scales	Aspired value from motivation	Scale of aspired value	(1.4)(1.5)
			Strategic development	(1.4)
			Introducing new issues of integration	(1.2)
			Other	
	Hierarchy in functionality	Functionality	Necessity	(1.1)(1.3)(1.4)(1.5)
			Availability	(1.2)
			Value dominance	(1.5)
			Independent functionality	(1.5)
			Other	
	Different lifecycles drive modularity	Lifecycles	Modular adaptability	(1.3)(1.4)(1.5)
			(Un)lock of possibilities	(1.1)(1.4)
			Difference in lifespan	(1.4)
			Other	
	Project responsibilities are defined in line with institutional responsibilities	Institutional responsibilities	Limiting policies	(1.1)(1.4)
			Maintenance and control per institution	(1.1)(1.4)
			Funding per institution	(1.1)(1.4)(1.5)
			Modular coupling public-private	(1.4)

			Code	Interviewee (c.i)
			Independent responsibilities	(1.5)
			Other	
Topic: Conditions for the integrated design process				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
Momentum, a creative alternative, and a detail design agreement form the base for integration	Detail agreement secures quality of integration	Agreement	Governance agreement	(1.1)(1.4)(1.5)
			Detailed design	(1.1)(1.4)(1.5)
			Fix quality	(1.5)
			Tailor-made solutions	(1.5)
			Short cyclic decision-making	(1.5)
			Other	
	The feasibility is determined by a momentum in cost, technology, and programs	Feasibility	Part of larger program	(1.1)(1.4)
			Cost efficiency	(1.1)(1.2)(1.3)(1.4)(1.5)
			Technical	(1.1)(1.4)(1.5)
			Momentum	(1.4)(1.5)
			Funding should fit into larger programs	(1.4)(1.5)
			Other	
An open, active, and collaborative, but strictly structured setting to discuss the integration of different interests	The individual ambition of people is key	Ambitious people	Level of ambition	(1.1)(1.4)(1.5)
			Strived level of quality	(1.1)(1.4)(1.5)
			Willingness to create multiple qualities	(1.1)(1.4)(1.5)
			Take responsibility	(1.5)
			Other	
	Open interaction and understanding in project team is key	Aligned mindset	Shared ambition	(1.1)(1.2)(1.3)(1.4)(1.5)
			Integral way of working	(1.1)(1.2)(1.4)(1.5)
			Abstract as long as possible	(1.1)
			Understanding each other's systems	(1.1)(1.2)(1.3)(1.4)(1.5)
			Mutual communication of design choices	(1.1)(1.4)(1.5)
			Respect each other's interests	(1.4)(1.5)
			Trust	(1.4)(1.5)
			Open mind	(1.5)
			Flow	(1.5)
			Other	
	Very strict project management structure from the beginning is key	Preparation	Well organized from the beginning	(1.4)(1.5)
			Prepare in detail for procedures	(1.5)
			Investigation of every topic	(1.5)
			Capable people	(1.5)

			Incorporate ideas at the start	(1.5)
			Team organization	(1.5)
			Clear roles	(1.5)
			Use of proven method	(1.5)
			Other	
	Actively involving stakeholders is key	Stakeholder involvement	Open communication	(1.2)(1.5)
			Clear communication	(1.5)
			Active communication	(1.5)
			Sensitivity to environment	(1.5)
			Informing	(1.2)(1.5)
			Convincing	(1.5)
			Looking for collaboration	(1.5)
			Compensation	(1.5)
			Participation	(1.2)(1.4)(1.5)
			Present at construction site	(1.5)
			Other	
	No need to document process	Evaluative notes	Process not documented	(1.1)(1.4)
			Other	

C.2 Benthemplein

Case: Benthemplein				
Topic: Motivation for integration				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
The combination of the lack of space and resources, and the desire to create a showcase form the main motivation for integration	Desire to create a showcase to increase awareness	Opportunities	Available situation	(2.1)
			Showcase	(2.1)(2.2)(2.3)
			Awareness	(2.1)(2.2)(2.3)
			Other	
	Mainly the lack of space and resources drives a need for integration	Conflicts	Space conflicts	(2.1)(2.2)(2.3)
			Interference of systems	(2.1)(2.2)(2.3)
			Conflicting interests	(2.1)(2.3)
			License-to-operate	(2.1)(2.2)
			Lack of resources	(2.2)
			Experience of conflict in former projects	(2.2)
			Other	
Topic: Design aspects in relation to integration				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
The aspired integration is context dependent	A visible and strategic addition of functions	Aspired value from motivation	Visibility	(2.1)(2.2)(2.3)
			Strategic development	(2.1)(2.2)
			Introducing new issues of integration	(2.1)(2.2)
			Other	
	Hierarchy in functionality	Functionality	Necessity	(2.1)(2.2)
			Availability	(2.1)(2.2)
			Other	
	Different lifecycles determine integration choices	Lifecycles	Differentiation in lifecycles	(2.1)
			Functional lifetime	(2.1)
			Technical lifetime	(2.1)(2.3)
			Modular adaptability	(2.1)
			Political lifetime	(2.3)
			Other	
	Project responsibilities are defined in line with institutional responsibilities	Institutional responsibilities	Funding per institution	(2.1)(2.2)(2.3)
			Governance per institution	(2.1)(2.3)
			Maintenance and control per institution	(2.1)(2.2)(2.3)
			Limiting policies	(2.1)
			Independent responsibilities	(2.1)(2.2)(2.3)

Theme	Sub-theme	Category	Code	Interviewee (c.i)
			Other	
Topic: Conditions for the integrated design process				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
Traditional internal organization and value frameworks form bottlenecks for development	Internal agreement can be a bottleneck	Agreement	Governance agreement	(2.1)(2.2)
			Management agreement	(2.3)
			Informal agreement	(2.3)
			Other	
	Subsidies and extra funding required to obtain cost efficiency, and not every location is suitable to apply	Feasibility	Subsidies	(2.1)(2.3)
			Selection of potential locations to apply	(2.1)(2.2)(2.3)
			Cost efficiency	(2.1)(2.2)(2.3)
			Technical	(2.1)
			Part of larger program	(2.1)(2.2)(2.3)
			Coupling to other programs	(2.2)
			Extra budget	(2.2)(2.3)
			Uncouple from standard	(2.3)
			Lifecycle approach	(2.3)
			Risk analysis	(2.3)
			Momentum	(2.3)
			Combined budgets	(2.3)
			Testing ground	(2.1)(2.2)(2.3)
			Other	
Open, but strategically information in combination with assigning budgets to create commitment are key	Forced commitment can be obtained by assigning budgets	Ambitious people	Willingness to create multiple qualities	(2.1)(2.2)
			Level of ambition	(2.1)
			Creating room for design	(2.1)
			Willingness to pay	(2.1)
			Forced commitment	(2.1)
			Strived level of quality	(2.3)
			Other	
	Aligned mindset can be obtained when different ambitions come together	Aligned mindset	Attitude and behavior	(2.1)(2.3)
			Clear roles	(2.2)
			Collaborative mindset	(2.2)
			New management group	(2.3)
			Other	
	Incorporate sensitivity to the environment to obtain collaborative participation by open communication, but informing	Stakeholder involvement	Sensitivity to environment	(2.1)(2.2)
			Multiple disciplines	(2.1)(2.3)
			Participation	(2.1)(2.2)
			Informing strategically	(2.1)
			Collaboration	(2.1)(2.2)(2.3)
			Accessibility	(2.1)(2.2)
			Broad network	(2.2)
			Convincing	(2.2)
			Open communication	(2.3)

	strategically		Specific expertise	(2.3)
			Other	
Ad hoc approach causes many new challenges	Ad hoc approach due to new type of project	Preparation	No proven method	(2.1)(2.3)
			Ad hoc approach	(2.3)
			New type of project	(2.2)(2.3)
			Maintenance and control involved at front	(2.3)
			Early involvement of disciplines	(2.3)
			Other	
	The ad hoc approach results in confrontation with issues and learning points for sequential development	Evaluative notes	Falling in between departments	(2.3)
			Not maintaining responsibilities	(2.1)
			More maintenance friendly	(2.1)(2.2)
			More green	(2.1)
			Learning on the way	(2.1)(2.3)
			Perceived responsibility	(2.3)
			No formal obligations	(2.3)
			Lagging process of governance	(2.3)
			Discrepancy between ideation / operation	(2.3)
			Other	

C.3 Biomakery Strijp-S

Case: Biomakery Strijp-S				
Topic: Motivation for integration				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
The motivation for integration is driven by the combination of linking to other cases and the need to solve the degenerative interrelation of systems	Opportunities to link to other cases and anticipate future policies	Opportunities	Available situation	(3.1)(3.3)(3.4)
			Available resources	(3.1)(3.2)(3.3)(3.4)(3.5)
			Available construction equipment	(3.1)
			Available technology	(3.2)(3.4)
			Chronological benefit	(3.2)
			Showcase	(3.1)(3.2)(3.4)
			Awareness	(3.1)
			New policies	(3.2)
			Other	
	Different systems have a degenerative interrelation	Conflicts	Space conflicts	(3.4)
			Interference of systems	(3.1)(3.2)(3.3)(3.5)
			Conflicting interests	(3.1)(3.2)(3.3)(3.4)(3.5)
			Lack of resources	(3.1)(3.3)(3.4)(3.5)
			Conflicting norms	(3.1)(3.3)(3.5)
			Legacy systems	(3.1)(3.4)
			Other	
Topic: Design aspects in relation to integration				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
The aspired integration is context dependent	Project becomes strategically when part of a broader ambition	Aspired value from motivation	Visibility	(3.1)(3.3)
			Strategic development	(3.1)(3.2)(3.3)
			Diversity	(3.2)
			Example project	(3.2)
			Introducing new issues of integration	(3.2)(3.3)
			Other	
	Dominant functions drive feasibility	Functionality	Necessity	(3.1)(3.5)
			Availability	(3.1)(3.5)
			Independent functionality	(3.1)(3.3)
			Functional dominance	(3.3)
			Other	
	Political lifetime can be a bottleneck	Lifecycles	(Un)lock of possibilities	(3.1)(3.2)(3.3)(3.4)(3.5)
			Functional lifetime	(3.1)(3.4)(3.5)
			Technical lifetime	(3.1)
			Political lifetime	(3.1)(3.2)(3.4)(3.5)
			Other	
	Project	Institutional	Uncertainty	(3.1)

	responsibilities are defined in line with institutional responsibilities	responsibilities	Funding per institution	(3.1)(3.5)
			Maintenance and control per institution	(3.1)(3.2)(3.4)(3.5)
			Risk per institution	(3.1)(3.4)
			Limiting policies	(3.1)(3.2)(3.3)(3.5)
			Independent responsibilities	(3.1)(3.2)(3.3)(3.4)(3.5)
			Exclusive rights	(3.1)
			Other	
Topic: Conditions for the integrated design process				
Theme	Sub-theme	Category	Code	Interviewee (c.i)
Momentum in decision-making is key	Agreement is subordinate to political lifetime	Agreement	Governance agreement	(3.1)(3.2)(3.3)(3.4)(3.5)
			Detailed design	(3.1)
			Public-private partnership	(3.3)
			Public-public partnership	(3.4)
			Force decision-making	(3.5)
			Other	
	The momentum in decision-making as part of larger program or coupling to other programs can be a bottleneck	Feasibility	Subsidies	(3.1)
			Selection of potential locations to apply	(3.1)(3.2)(3.4)
			Cost efficiency	(3.1)(3.2)(3.3)(3.4)(3.5)
			Technical	(3.1)(3.3)(3.4)(3.5)
			Part of larger program	(3.1)(3.2)(3.3)(3.4)(3.5)
			Coupling to other programs	(3.1)(3.2)(3.3)(3.4)(3.5)
			Momentum	(3.1)(3.2)(3.3)(3.4)(3.5)
			Testing ground	(3.1)(3.2)(3.3)(3.4)(3.5)
			Jurisdictions	(3.1)
			Labeling of budgets	(3.1)(3.2)(3.4)
			Extra budget	(3.2)(3.5)
			Uncouple from standard	(3.2)(3.4)
			Competition	(3.3)
			Assigning budget	(3.3)(3.4)
			Coupling to business models	(3.3)
			Lagging return on investment	(3.3)
			Coupling to budgets	(3.4)
			Scalability	(3.5)
			Other	
Momentum in stakeholder ambitions and involvement do not match with process	The individual ambition of people, and the willingness to do and dare something	Ambitious people	Willingness to create multiple qualities	(3.2)(3.3)(3.4)(3.5)
			Level of ambition	(3.1)(3.2)(3.3)(3.4)(3.5)
			Take responsibility	(3.1)(3.3)(3.4)
			Strived level of quality	(3.3)(3.4)(3.5)
			Opportunism	(3.2)(3.3)

of governance	innovative is key		Prioritizing	(3.3)(3.5)
			Courage	(3.3)
			Positive attitude	(3.4)
			Other	
	Agreement to use momentum is lagging behind when there is not a shared ambition	Aligned mindset	Shared ambition	(3.1)(3.2)(3.3)(3.4)(3.5)
			Integral way of working	(3.3)(3.4)(3.5)
			Equal share per institution	(3.1)
			Respect each other's interests	(3.2)(3.3)(3.5)
			Understanding each other's systems	(3.3)(3.5)
			Working alongside each other	(3.3)(3.4)
			New management group	(3.3)(3.5)
			Other	
	Capable people and organizational capacity are key in this new type of project	Preparation	Capable people	(3.1)(3.2)(3.3)(3.4)
			Organizational capacity	(3.1)(3.2)(3.3)(3.4)(3.5)
			Incorporate ideas at the start	(3.1)
			New type of project	(3.1)(3.4)
			Well organized from the beginning	(3.1)(3.2)(3.3)
			No proven method	(3.2)(3.3)(3.5)
			Reference projects	(3.1)
			Workshops	(3.2)(3.4)
			Back-up system	(3.2)(3.4)
			Clear roles	(3.3)
			Team organization	(3.3)
			Use of calculation models	(3.2)(3.3)
			Structure for integration	(3.3)
			Trust	(3.4)(3.5)
			Broad view	(3.4)
			Confidence	(3.4)
			No risk-based design	(3.4)
			Use of methods	(3.4)
			Other	
	Actively involving stakeholders in an open, but strategically way is key	Stakeholder involvement	Sensitivity to environment	(3.2)(3.5)
			Clear communication	(3.3)(3.5)
			Open communication	(3.5)
			Looking for collaboration	(3.1)(3.2)(3.3)(3.4)(3.5)
			Incorporate strategically	(3.1)
			Collaboration	(3.1)(3.2)(3.4)(3.5)
			Multiple disciplines	(3.3)
			Convincing	(3.1)(3.2)(3.4)
			Early involvement of disciplines	(3.1)(3.4)

			Platform	(3.3)
			Letting loose control	(3.4)
			Participation	(3.4)
			Acceleration	(3.4)
			Openness	(3.4)
			Other	
	The lagging process of governance can be a bottleneck	Evaluative notes	Not maintaining responsibilities	(3.1)
			No formal obligations	(3.1)
			Lagging process of governance	(3.1)(3.2)(3.4)(3.5)
			Discrepancy between ideation / operation	(3.1)(3.3)
			Change of scope	(3.1)
			Framing	(3.2)
			Not many reference projects	(3.2)(3.3)
			Learning on the way	(3.3)(3.5)
			Other	

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Glossary

The glossary presents terms in the definition of how these terms are used in this dissertation:

Abduction	Hypothetical reasoning
Absolution	To ignore a problem or mess and hope it will take care of itself and go away of its own accord
Abundance	Referring to a system state in which interrelated constraints do not limit the incorporation of value with respect to different forms of aspired value
Approach	Way of dealing with something
Artifact	Referring to the human-designed intervention that connects different reference states that were not naturally causally related with each other
Artifact frame	The combination of the 'working principle' and the 'aspired value'
Aspired value	Value that is strived for through design
Cascading effect	'Waterfall' of solving problems or incorporating opportunities in interrelated systems
Coherence	Purposefulness or 'unity' of a design
Combinative	Combining sub-solutions or features in a design process
Compatibility	The relation between multiple artifact frames
Concurrent engineering	Process management technique that seeks to structure the parallel development of different parts (however defined) of a design, the company organization, marketing and production facilities
Conditionality	The relation between intervention and a particular reference state

Creation-driven design	Design that is referring to intervention as the creation of possible desirables that people are not aware of before
Creative ideas	A sudden occurrence of a 'whole'
Defined abduction	Design within a defined artifact frame
Design	The definition of the reference state dependent intervening conditionality in order to obtain a higher system state
Design space	Constructed system of constraints as defined by the problem space or opportunity space, and the interrelated solution space
Designer framing	Framing as the awareness of mental infrastructures or lenses, including its own, and the ability to combine this with the adoption of a terminology and a way of reasoning to develop a set of possible actions
Desired value	Value that can be defined from the perspective of the stakeholder
Discovery-driven design	Design that is referring to intervention as the discovery of possibilities to realize desirables
Dissolution	To redesign either the entity that has the problem or mess, or its environment, in such a way as to eliminate the problem or mess and enable the system involved to do better in the future than the best it can do today, in a word, to idealize
Emergence	System behavior that is not present at the lower level, but is a product of the interactions of elements
Frame	Lens
Frame abduction	Design in which the definition of the artifact frame is part of the design itself
Frame awareness	Awareness about a certain lens through which someone reasons, recognizes, perceives, valuates, and forms an opinion

Frame compatibility	The way different lenses are related to each other
Framework	A basic conceptual structure
Framing	The application or creation of a certain, or different lens(es)
Heuristic	Characteristic of design that emphasizes that design is referring to an attempt to make a desirable future possible, instead of causing a certain future
Holistic	Dealing with or treating something as an undivided 'whole'
Imposed constraints	Constraints that are not intrinsic, but set by conditions out of the control of the designer
Inclusive	Reasonable accessibility to products and/or services in a wide variety of situations
Integral	As part of a 'whole'
Integrated	The compatibility of any multiple artifact frames
Integrated design	The framing of the compatibility of multiple artifact frames
Integration as a quality	Level of integration in a product
Intervention	Referring to an activity that frames natural causal relations
Intrinsic constraints	Constraints that are set by laws of nature
Issue	Something that is pressing, which needs to be addressed and taken care of
Leverage	The exertion of force by means of a lever
Meta-method	Method in which more specific methods and approaches show common ground
Method	The process used or steps taken in dealing with something

Methodological structure	The interrelated set of methodological frames that structure the design process
Momentum	Moment on which window of opportunity can be utilized
NIMBY	Not-In-My-BackYard: something that is perceived as unpleasant or hazardous by people in their own neighborhood, while raising no objections to similar development elsewhere
Object	Referring to the physical presence of something, but does not have to be artificial, or part of design
Opportunity space	System of constraints that defines the boundaries for defining the opportunity
Optimization	(Incremental) improvement of an already existing product or design concept
Platform	A base structure from which can be interacted collaboratively
Problem solving	Design that is referring to intervention to solve problems
Problem space	System of constraints that defines the boundaries for defining the problem
Product	Referring to the result of a process, which can be physical or not
Product integrity	'Wholeness' or 'rightness' in a product design
Resolution	To do something that yields an outcome that is good enough, that satisfies
Self-imposed constraints	Constraints that are set by the designer to enable creativity or frame a design
Solution	To do something that yields or comes close as possible to the best possible outcome, something that optimizes, but serves a certain optimal sub-solution

Solution space	System of constraints that defines the boundaries for developing a solution
Symbiotic	Denoting a mutually beneficial relationship between different organisms
Synergy	The interaction of elements in a way that, when combined, produce a total effect that is greater than the sum of the individual elements
System	A set of different elements so connected or related as to perform a unique function not performable by the elements alone
Task	The prescribed or pre-defined reference state dependent intervening conditionality in order to obtain a higher system state
Tightly coupled	Interdependently related in terms of identity, physics, and/or logic
Universal	Products and environments for the needs of people, regardless of age, ability or status
Value	The worth, importance or usefulness of something
Values	Plural form of 'value': the worth, importance or usefulness of multiple aspects or: Fundamental layer of 'value': the worth, importance or usefulness of something on the layer of beliefs or social behavior
Window of opportunity	Defined window for incorporating opportunities that can be described by the opportunity space
Working principle	Way in which the artifact can lead to the aspired value

About the Author

Joannes Visser was born in Dirksland on the 12th of April in 1988. He grew up in a small village at Goeree-Overflakkee, called Stad aan 't Haringvliet. After he graduated from the Prins Maurits in Middelharnis, he moved to Delft to study Civil Engineering at Delft University of Technology. There he obtained a Bachelor's degree in Civil Engineering and continued at the same faculty with his Master's in Construction Management and Engineering. In his Master's he researched during his internship at Royal HaskoningDHV the internal innovation and innovation management of the company. In this role he also got the opportunity to present recommendations for increasing and rewarding internal innovation to the responsible directors. Subsequently, he worked as a student assistant, and later coordinator of the first year's student design course at the faculty of Civil Engineering and Geosciences. He obtained his Master's degree in 2014 with finalizing his graduation thesis that was given the title 'The Value of Perception', which was executed at the Port Authority of Rotterdam. At that time, the Port Authority of Rotterdam was in the final development phase of project Maasvlakte II, and stakeholder management was done in accordance with the Mutual Gains Approach. The perception of value of stakeholders became the core topic of his graduation research and showed the relation between framing and the perception of value. During his graduate research, prof.dr.ir. Marcel Hertogh asked him to conduct a PhD research into integrated design. The aspects of framing and value also became core themes in the PhD research. Framing and design were researched on their interrelation in order to obtain integration and the increase of value for all stakeholders.

However, before starting the PhD process, Joannes first worked for about a year on a vision document for the development of the minor Integrated Infrastructure Design at Delft University of Technology, as requested by the Deltas Infrastructure and Mobility Initiative (DIMI). DIMI is an interfaculty group that focuses on integrated design challenges and became the main sponsor of his PhD research as well. Subsequently he also became a coach for students in the introductory course of this minor and participated in meetings with respect to the development of the minor.

During his time as a PhD researcher, Joannes conducted multiple additional activities. He became over the period of one year the part-time coordinator of the first year's design course of the faculty of Civil Engineering and Geosciences. In this role he had to instruct 20 student assistants and 20 external professionals on a weekly base, and was responsible for the design of the case descriptions and exams. In addition, he also gave several presentations for respectively Rijkswaterstaat, the course Delta Interventions, the minor Integrated Infrastructure Design, and the DIMI Advisory Board. Together with prof.dr.ir.

Marcel Hertogh and dr. Nikki Brand, he got the opportunity to write a chapter in the book 'Projects and People: Mastering Success' of prof.dr.ir. Hans Bakker and dr. Jaap de Kleijn.

During his PhD process, Joannes was selected for the IDEA League with 24 other PhD researchers from the European universities ETH Zürich, RWTH Aachen, Chalmers University, and Delft University of Technology. In this way he got the opportunity to participate in a program called 'Urban Systems and Sustainability'. Over a year, periodic efforts were organized with visits to Delft, Singapore, Guangzhou, and Aachen, in which multi-disciplinary teams of PhD students worked together on research regarding the theme of the program. In addition, he also visited the Design Research Society Conference in Brighton and the International Conference on Engineering Design in Delft to increase his knowledge and network in the design sciences. To obtain more contacts in the integrated design practice as well, he participated in the summer school 'Transit Oriented Development', which was a collaboration between Rijkswaterstaat and Delft University of Technology. In this way, he got the opportunity to explore the field of integrated design and to obtain a broad network in different domains to reflect and discuss his PhD research.

Joannes also supervised students from different faculties in their graduation work with respect to integrated design. In addition, he also became a tutor in integrated design during student projects in the Volta Delta, Ghana and Sydney, Australia. The coaching supported students in their own work, but also supported reflection on the PhD research.

Acknowledgements

Although conducting a PhD was never on my mind when doing my Master's at Delft University of Technology, during my graduation research prof.dr.ir. Marcel Hertogh asked me to think of the possibility to start a PhD research into integrated design. I decided to take this chance and from that moment a new journey started. I call it a journey because it also felt like a journey. During my PhD I had the opportunity to travel a lot. Different in terms of activity, but it felt many times quite similar in terms of experience. The exploration of new academic grounds, entering and defining places few or no other people have been before, and developing from a rookie to a mature explorer. It was a really exiting time, and I would like to thank some people that supported me during this journey.

First of all, I would like to thank my promotors prof.dr.ir. Marcel Hertogh and prof.dr. Petra Badke-Schaub. I would like to thank you Marcel for your trust in me and the research, the freedom you gave me to organize and conduct this research, and your never lasting positivism and enthusiasm to add to the content of my work. Without you there would not have been this dissertation. Your trust in, and positivism to, the people you work with are inspirational.

Petra became a bit later involved in my PhD process, but added significantly to my work. In the first place from the perspective of know-how in the design sciences, and secondly in sharpen my validation. Also the discussions with respect to the organization of my case studies was very helpful. However, I would like to thank you Petra in particular for your willingness to support the development of my work. As already said, although involved in a later stage of this PhD research you were willing to add to, and sharpen my work, and making time to discuss it. This sounds normal, but your involvement and your responsibility to taking care of someone else's work are special. This is what you and Marcel both share, and what inspired me when supervising students myself.

A third person, which was not part of the committee, but very important in the support of my research, was our secretary, Sandra Schuchmann. Thank you Sandra for your support, creativity, and all the jokes we had over the years. It was really fun the work with you and I still have to laugh about all our funny moments when typing this.

In addition, I would like to express my gratitude to the Deltas Infrastructure and Mobility Initiative (DIMI) for supporting me financially. In the beginning in the role of Junior Researcher, to give input to the development of the minor 'Integrated Infrastructure Design', and later to the development of my PhD research. I would also thank my colleagues of DIMI for their positivism regarding me, and my work. The DIMI meetings were always really fun and felt like a family of enthusiast people that are eager to work on new types of projects and designs. In particular I would like to thank Nikki Brand for helping me with the review of my coded transcriptions, and Egbert Stolk for giving feedback and discussing my research into different definitions of design.

The supportive attitude also holds for my colleagues at the department of Materials, Mechanics, Management and Design (3MD). Thank you all for your interest and support over the years. Hopefully integrated design can become more and more embedded in the academic body of our research group.

At last, I especially would like to thank my parents, Leen en Ina. Thank you both for giving me the space to conduct this research, your interest when I was talking about it, and just for being my parents. I could not have wished for better ones. Thank you dad for showing me the beauty of buildings and architecture, which really formed me in that field. And I would like to thank you mum for all your patience and the listening ear. Mum and dad, I will always think back with great pleasure to these special years together. Hopefully we will get many more happy and healthy years together in a new setting.

As a final word I would like to come back to the earlier mentioned exploration. I never expected that this PhD trajectory would have brought me so much in terms of academic development. However, the energy from the curiosity to explore was in the end the main driver for this work. I really enjoyed it and I am looking forward keep on exploring in this field. Although the world seems to become a village with all the travel options and information sources we can use today, exploration stills exists for everyone in the discovery of new knowledge. Keep that spirit and you will be surprised!

Joannes Visser

Delft, November 2020

Integrated design is a frequently used term in academics and practice. However, a common ground in the application of terminology, methodology, and description of insights from practice with respect to integrated design is lacking. Therefore, this dissertation describes a framework for integrated design that can be used as a platform for discussion and development. The framework is the result of the exploratory research into the what, why, and how of integrated design, and can be used by anyone who has to deal with integrated design and would like to have more grip on this concept.