Design for change

for a more sustainable resource usage in construction

Patrick de Laat

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SUSTAINABLE RESOURCE USAGE IN CONSTRUCTION

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*“The whole of science is nothing more than
a refinement of every day thinking.”*

Albert Einstein, 1936 (p. 349)

Summary

The current usage of natural resources cannot be maintained forever – our resources are depleting. A substantial share of resource usage, and therefore the problem, is related to the construction sector. Meanwhile, there are signs that buildings are being demolished prematurely. This premature demolition of buildings is a waste of resources. This dissertation's end goal is to contribute towards mitigating the problem of resource depletion. Changeability has been selected as the means through which to pursue this goal. This research aims to both understand design and to create support to help improve design, specifically regarding the topic of design for change in relation to sustainable resource usage.

In Chapter 2, i.e. *“Resource depletion, where is an intervention most effective?”*, the topic of resource depletion is dealt with. Chapter 2's aim is to rank areas of the resource system, according to how much of an impact can be expected from interventions in the area, in relation to the problem of depleting resources. Firstly, principles of Structured Analysis are used to model the process of resource usage, and, from this model, five intervention areas are defined. Secondly, these intervention areas are ranked in terms of effectiveness, through the use of Analytic Hierarchy Process. To be most effective, one must prioritize intervention areas as follows: (1) material inputs to the operation phase; (2a) process inputs to the operation phase and (2b) products' longevity; (4) process inputs to the manufacturing phase; and (5) material inputs to the manufacturing phase. In this study, changeability is not pursued for the sake of changeability. Changeability is pursued for the sake of mitigating the problem of resource depletion. Chapter 2's outcome can guide this pursuit of changeability in the right direction.

In Chapter 3, i.e. *“The evolution of ordinary houses, does it justify demolition?”*, the topic of longevity in relation to change is dealt with. Chapter 3's aim is to determine how the ordinary house, in the Netherlands, has changed throughout the last 100 years. This information is then used to discuss: to what extent the house's evolution justifies demolition. A non-random sampling method is used to select 68 housing projects from the city of Nijmegen. These projects contain a total of 8270 housing units ($\approx 10\%$ of Nijmegen's housing stock). Of each project, a standard housing unit is analysed in terms of: (1) length and width; (2) floor-to-ceiling height; (3) utilitarian rooms; (4) spatial layout; (5) type of structure; (6) roof structure; (7) insulation; and (8) separating wall's thickness. Chapter 3's outcome provides a first indication of to what extent a building's longevity is determined by its design. This knowledge contributes to a more valid assessment of changeability's contribution towards mitigating the problem of

resource depletion.

In Chapter 4, i.e. “*How to set up criteria for evaluating a building’s changeability?*”, the topic of changeability is dealt with. In Chapter 4, a method is proposed in which: (1) scenarios are developed to identify potential problems; and (2) evaluation criteria are based on design solutions to those potential problems. To support and guide the development of both scenarios and design solutions, changeability levels and types of design tactics are defined. A top-down approach is used to define changeability levels, while a bottom-up approach, i.e. the constant comparative method, is used to define types of design tactics. This research’s main contribution is that it provides a method for unpacking the black box of design for change. This method is presented in Chapter 4.

In Chapter 5, i.e. “*How adjustable is the Environmental Building?*”, the application of the evaluation method, that has been presented in Chapter 4, is tested. To do so, the Environmental Building’s adjustability is evaluated by following the steps described in this method. Adjustability is the first of four changeability levels, as defined in Chapter 4. The Environmental Building has the ability to comply with changing requirements of the individual in terms of indoor climate conditions. However, it lacks the ability to comply with changing requirements of the individual in terms of space, privacy and interaction. Chapter 5 demonstrates that by using this method, specific strengths and weaknesses of the building’s design can be identified.

Samenvatting

Het huidige verbruik van natuurlijke grondstoffen kan niet blijvend worden doorgezet – onze grondstoffen raken op. Een substantieel deel van dit verbruik, en daarmee het probleem, is gerelateerd aan de bouwsector. Ondertussen zijn er ook tekens dat gebouwen vroegtijdig worden gesloopt. Deze vroegtijdige sloop is een verspilling van grondstoffen. De uiteindelijke doelstelling van deze dissertatie is om bij te dragen aan een vermindering van de uitputting van grondstoffen. Veranderbaarheid is de manier waarop dit doel wordt nagestreefd. Dit onderzoek heeft zowel het streven om het ontwerpen te begrijpen, maar ook om ondersteuning op te zetten die helpt met het verbeteren van het ontwerpen, en dit alles specifiek in relatie tot het volgende onderwerp: ontwerpen voor verandering in relatie tot duurzaam grondstofgebruik.

In hoofdstuk 2, genaamd “*Resource depletion, where is an intervention most effective?*”, wordt het volgende onderwerp behandeld: de uitputting van grondstoffen. Het doel van hoofdstuk 2 is om de gebieden van het grondstoffsysteem te rangschikken in hoeverre een impact, op het probleem van de uitputting van grondstoffen, verwacht kan worden van interventies in het betreffende gebied. Als eerste zijn principes van “*Structured Analysis*” toegepast om het grondstoffenverbruik proces in kaart te brengen, en op basis hiervan zijn vijf interventiegebieden gedefinieerd. Als tweede zijn deze gebieden gerangschikt op effectiviteit door middel van “*Analytic Hierarchy Process*”. Om het meest effectief te zijn moet men de interventiegebieden als volgt prioriteren: (1) materiaalinput in de gebruiksfase; (2a) procesinput in de gebruiksfase en (2b) de levensduur van producten; (4) procesinput in de vervaardigingsfase; en (5) materiaalinput in de vervaardigingsfase. In dit onderzoek wordt veranderbaarheid niet nagestreefd omwille van veranderbaarheid. Veranderbaarheid wordt nagestreefd met als doel om bij te dragen aan een vermindering van de uitputting van grondstoffen. Het resultaat van hoofdstuk 2 moet ervoor zorgen dat dit streven naar veranderbaarheid zijn doel niet voorbij schiet.

In hoofdstuk 3, genaamd “*The evolution of ordinary houses, does it justify demolition?*”, wordt het volgende onderwerp behandeld: levensduur in relatie tot verandering. Het doel van hoofdstuk 3 is om vast te stellen hoe het alledaagse huis, in Nederland, veranderd is gedurende de afgelopen 100 jaar. Vervolgens wordt deze informatie gebruikt om te bediscussieren in hoeverre de sloop van het huis gerechtvaardigd is door de evolutie van het huis. Door middel van een niet-willekeurige steekproefmethode zijn 68 woningbouwprojecten geselecteerd in de stad Nijmegen. Gezamenlijk omvatten deze projecten een totaal van 8270 individuele woningen (≈10% van de woningvoorraad in

Nijmegen). Binnen elk project is een standaardwoning geanalyseerd op de volgende aspecten: (1) lengte en breedte; (2) vloer-tot-plafond hoogte; (3) utilitaire ruimtes; (4) ruimtelijke indeling; (5) constructietype; (6) dakconstructie; (7) isolatie; en (8) dikte van de woningscheidende wand. Hoofdstuk 3 geeft een eerste indicatie van in hoeverre het ontwerp bepalend is voor de levensduur van een gebouw. Deze kennis draagt bij aan een meer valide beoordeling van de bijdragen van veranderbaarheid aan de vermindering van de uitputting van grondstoffen.

In hoofdstuk 4, genaamd “*How to set up criteria for evaluating a building’s changeability?*”, wordt het volgende onderwerp behandeld: de veranderbaarheid van gebouwen. In hoofdstuk 4 wordt een methode voorgesteld waarin: (1) scenario’s ontwikkeld worden om potentiële problemen te identificeren; en (2) evaluatiecriteria gebaseerd zijn op ontwerpoplossingen voor deze potentiële problemen. Om de ontwikkeling van zowel scenario’s als ontwerpoplossingen te ondersteunen en te sturen zijn veranderbaarheidslevels en type ontwerptactieken gedefinieerd. Een top-down aanpak is gebruikt om veranderbaarheidslevels te definiëren, terwijl een bottom-up aanpak, de “*constant comparative method*”, gebruikt is om type ontwerptactieken te definiëren. De hoofdbijdrage van dit onderzoek is een methode om de black box van ontwerpen voor verandering uit te pakken. In hoofdstuk 4 wordt deze methode gepresenteerd.

In hoofdstuk 5, genaamd “*How adjustable is the Environmental Building?*”, wordt de toepassing van de evaluatiemethode getest, die in hoofdstuk 4 is gepresenteerd. Hiervoor is de afstelbaarheid van het “*Environmental Building*” geëvalueerd door de in de methode beschreven stappen te volgen. Afstelbaarheid is de eerste van de vier in hoofdstuk 4 gedefinieerde veranderbaarheidslevels. Het “*Environmental Building*” heeft het vermogen om zich te schikken naar veranderende eisen van het individu omtrent het binnenklimaat. Echter ontbreekt bij dit gebouw het vermogen om zich te schikken naar veranderende eisen van het individu omtrent ruimtegebruik, privacy en interactie. Hoofdstuk 5 laat zien dat specifieke sterktes en zwaktes van het gebouwoontwerp geïdentificeerd kunnen worden met behulp van de methode.

Table of contents

1. Introduction	2
1.1. Introduction	4
1.2. Goal	5
1.3. Methodology	10
1.4. Structure	14
2. Resource depletion, where is an intervention most effective?	16
2.1. Introduction	20
2.2. Method	21
2.3. Results	23
2.4. Discussion and conclusion	38
3. The evolution of ordinary houses, does it justify demolition?	40
3.1. Introduction	43
3.2. Method	46
3.3. Results	52
3.4. Discussion and conclusion	66
4. How to set up criteria for evaluating a building's changeability?	70
4.1. Introduction	73
4.2. Method	78
4.3. Results	81
4.4. Discussion and conclusion	93
5. How adjustable is the Environmental Building?	96
5.1. Introduction	100
5.2. Method	101
5.3. Results	103
5.4. Discussion and conclusion	120
6. Discussion and conclusion	122
6.1. Discussion	123
6.2. Conclusion	128

References	132
Appendix 1: Cases' information	148
Appendix 2: Design tactics' mentions	156
Appendix 3: Probability estimates	186

CHAPTER

1

Introduction.

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1.1. Introduction

Many authors have pointed out that the current usage of natural resources cannot be maintained forever (Boulding, 1966; Diederer, 2010; McDonough and Braungart, 2002; Meadows et al., 1972; Stahel, 1984). Some claim that society's standards are too high and that this is part of the problem (e.g. Diederer, 2010), while others deny that lower standards are necessary to resolve resource depletion (e.g. McDonough and Braungart, 2002). However, all agree that the take, make and dispose approach to achieving those standards is unsustainable. A substantial share of resource usage, and therefore the problem, is related to the construction sector (see Krausmann et al., 2009). Meanwhile, there are signs that buildings are being demolished prematurely. In Zurich (Switzerland), buildings do not even last half as long as they used to (Aksözen et al., 2017, p. 254, Fig. 10). Furthermore, a study (O'Connor, 2004) in Minneapolis–Saint Paul (USA) shows that especially non-residential buildings generally do not last as long as architects, engineers and developers expect them to last. In Finland, for example, non-residential buildings are on average only 43 years old when they are demolished (Huuhka and Lahdensivu, 2016, p. 87, Table 10). This premature demolition of buildings is a waste of resources.

According to Bocken et al. (2016, p. 309), there are three solutions to mitigate the problem of resource depletion: (1) closing resource flows, i.e. ensuring that the post-use material output feeds into manufacturing; (2) slowing resource flows, i.e. prolonging the use period of products and parts; and (3) narrowing resource flows, i.e. using less resources overall. This dissertation focusses on the second solution: slowing resource flows.

1.2. Goal

1.2.1. Introduction

This PhD research was part of an EU-funded project: Buildings as Material Banks (BAMB). As a result, both the goal and the background were pre-determined at the start of this research. The goal was to create a support method, for designers, that can evaluate a building's changeability¹, and the background was resource depletion. In other words, it was pre-determined that the changeability evaluation method needed to be a solution to the problem of resource depletion. The pre-determined project goal is based on the following premise: (1) a method for evaluating a building's changeability will improve the changeability of future buildings; (2) buildings with greater changeability will have greater longevity; and (3) when buildings have greater longevity, the problem of resource depletion is significantly reduced.

Thus, the project goal is to create a method that can evaluate a building's changeability, and therewith support the design of changeable buildings. However, changeable buildings is not the societal end goal, it is the means through which the end goal is pursued. This dissertation's societal end goal is to contribute towards mitigating the problem of resource depletion. Both these goals, i.e. the project goal and the societal goal, resulted in the following main research question: (Q-main) 'How can a building design's changeability, and the effect of this changeability on the problem of resource depletion, be evaluated?'. This main research question is composed of two smaller research questions: (Q1) 'How can the effect of a building design's changeability on the problem of resource depletion be evaluated?'; and (Q2) 'How can a building design's changeability be evaluated?'.

This dissertation's focus includes not two but three research topics: resource depletion, longevity and changeability. In Figure 1 is shown: how the topics of resource depletion, longevity and changeability are related to each other. In Figure 1, an arrow, with a minus symbol next to it, represents a negative relation. This means that an increase at the arrow's beginning will result in a decrease at the arrow's end. Thus, when longevity increases, resource depletion decreases. Also, when change increases, longevity decreases. Furthermore, in Figure 1, the relation itself, between change and longevity, is the target of another negative relation. This means the following: when changeability increases, the negative relation between change and longevity weakens.

¹ The project uses the term "transformation capacity" instead of changeability.

Figure 1. An overview of: how the topics of resource depletion, longevity and changeability are related to each other; and the outcomes that are aimed for in this dissertation, per topic. An arrow, with a minus symbol next to it represents a negative relation, e.g. when longevity increases, resource depletion decreases. Furthermore, the relation itself, between change and longevity, is the target of another negative relation. This means the following: when changeability increases, the negative relation between change and longevity weakens.

1.2.2. Changeability

The project goal is to create a method that can evaluate a building's changeability, and therewith support the design of changeable building. Thus, the primary goal is to understand design in relation to change, while a secondary goal is to create support to help improve design in relation to change. The term "*changeability*" is derived from the term "*design for change*". Design for change is a form of "*design for X*". The term design for X is used to describe the approach in which a particular perspective is adopted, represented by X, from which to improve the product design. The particular perspective is either: (1) a specific property; or (2) a life-cycle phase of the product (Tomiyaama et al., 2009, p. 552). The main challenge in the design for change approach is that its perspective is not at all specific. A changeable building is a building that is optimized from the perspective of future change. However, future change is neither a

single nor a specific event; future change represents countless possible events.

There are two ways to deal with this challenge: (1) the “*black box*” approach, i.e. primarily focussing on the inputs (design solutions) and the resulting impact; and (2) the “*white box*” approach, primarily focussing on the “*mechanisms*” that describe how and why certain design solutions have an impact (see Astbury and Leeuw, 2010).

The strength of the black box approach is that it does not try to specify something that cannot be specified comprehensively - it does not try to predict the future. However, validation is a problem with this approach. Monitoring the effects, of an intervention, on the lifespan of a building is practically not feasible. Alternatively, Wilkinson (see 2014b) focussed on a different resulting impact: the number of adaptation occurrences. However, more adaptation occurrences are not necessarily beneficial to a building’s lifespan. More adaptation occurrences may indicate that the building is highly adaptable, or it may indicate that the building was highly in need of adaptation. There are two types of changeability: (1) adaptability, i.e. a building’s ability to comply with changes through physical alterations to the building fabric; and (2) flexibility, i.e. a building’s ability to comply with changes without physical alterations to the building fabric (see Engel and Browning, 2008, p. 126; Heidrich et al., 2017, p. 288; Schmidt III, 2014, p. 66). Especially in relation to flexibility, it is very difficult to measure design solutions’ resulting impact.

Therefore, in this dissertation, the white box approach is used to deal with the non-specific optimization goal of design for change. Thus, the primary focus is not the link between design solution and resulting impact, but the link between design solution and future change. Thus, this dissertation’s goal is to create a method that can evaluate a building’s changeability, based on a deep understanding of the relation between future change and design solutions.

1.2.3. Resource depletion

This dissertation’s societal end goal is to contribute towards mitigating the problem of resource depletion. Changeability has been selected as the means through which to pursue this goal. However, are there not more effective means to achieve this goal? Furthermore, at times, changeability may conflict with other means of achieving the same goal. If so, at what cost may changeability be pursued, in order for it to still be considered a contribution towards mitigating the problem of resource depletion. To help deal with such questions, it helps to know which interventions are more effective. Therefore, a secondary goal of this dissertation is to prioritize interventions, in relation to the problem of depleting resources.

1.2.4. Longevity

Longevity is the link between the topics of changeability and resource depletion. Thus, in order for changeability to have an effect on resource depletion, change must have an effect on longevity. Furthermore, within this effect that change has on longevity, design must matter. When a building's physical qualities are not taken into account in the decision-making process of the building's demolition, there is no point in improving a building's design in relation to future change. The decision-making process of a building's demolition is a topic in its own right. However, since the topic is such an essential link between the topics of changeability and resource depletion, some understanding, of the role of a building's physical qualities within the decision-making process of the building's demolition, is important. Therefore, another secondary goal of this dissertation is to verify whether or not the evolution in building design is a likely cause of premature demolition.

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1.3. Methodology

1.3.1. Introduction

Research that not only aims to understand design, but also to create support to help improve design is termed “*design research*” (Blessing and Chakrabarti, 2009, pp. 2-6). According to the book “*DRM, A design research methodology*” (Blessing and Chakrabarti, 2009, pp. 18-19), a comprehensive design research study includes the following stages: (1) research clarification; (2) descriptive study I; (3) prescriptive study; and (4) descriptive study II. Furthermore, these stages are expected to result in the following outcomes (p. 15), respectively: (1) goals; (2) understanding; (3) support; and (4) evaluation. Furthermore, in DRM, a distinction is made between initial, review-based and comprehensive studies (p. 18).

1.3.2. Research clarification

The first stage in a design research study is the research clarification stage. The objective of this stage is to identify the goals that the research is expected to realise (Blessing and Chakrabarti, 2009, p. 30). This dissertation’s focus is the topic of changeability. More specifically, this dissertation’s focus is the topic of changeability in relation to the topics of longevity and resource depletion. This dissertation aims to contribute to both the overall subject matter and the three separate topics. To do so, the book “*DRM, A design research methodology*” prescribes multiple research clarification stages, i.e. one per topic.

In this dissertation, the research clarification is dealt with in the following manners. First, this chapter, i.e. Chapter 1, contains the general research clarification related to the overall subject matter. Second, the Chapters 2, 3 and 4 contain brief, and specific, research clarifications related to the topics of resource depletion, longevity, and changeability, respectively. Third, the chapters regarding resource depletion and longevity provide an extensive research clarification related to the overall subject matter, i.e. changeability in relation to longevity and resource depletion.

1.3.3. Descriptive study I

The second stage in a design research study is the (first) descriptive study stage. The objective of this stage is to increase understanding of design and its success factors, in relation to the specific topic (Blessing and Chakrabarti, 2009, p. 31). This dissertation aims to increase understanding regarding the overall subject matter, i.e. changeability in relation to longevity and resource depletion, by gaining: (1) an initial understanding

of the topic of building longevity; (2) a review-based understanding of the topic of changeability; and (3) a comprehensive understanding of the topic of resource depletion. For resource depletion, an “*explicative model*” can be developed to gain a comprehensive understanding of the topic. An explicative model is a model that describes how the process works, and why the process works the way it does (see Klaasen, 2002, p. 184). This model will be developed to answer the following research question: (Q1a) ‘What are the different intervention areas for the problem of resource depletion?’. The topic of changeability however, lacks a specific optimization goal. Therefore, it is not possible to develop a comprehensive understanding of how future change affects buildings. Instead, the goal in this stage will be to gain a review-based understanding, specifically of the design solutions, or success factors, of changeability. This goal is stated in the following research question: (Q2a) ‘What are the types of design tactics used in design solutions of changeability?’.

For longevity, the historical evolution of buildings can be examined to gain an initial understanding of the topic in relation to change. This examination will be conducted to answer the following research question: (Q1c) ‘Is the evolution of buildings’ design a justifiable reason for a building’s demolition?’.

1.3.4. Prescriptive study

The third stage in a design research study is the prescriptive study stage. The objective of this stage is to develop design support, in relation to the specific topic. This dissertation aims to set up support regarding the overall subject matter, i.e. changeability in relation to longevity and resource depletion, by developing: (1) initial support for the topic of resource depletion; and (2) comprehensive support for the topic of changeability.

For resource depletion, the initial support will be based on an explicative model. In the previous stage, different intervention areas are identified. In this stage, they are compared and ranked. The goal of this step is to answer the following research question: (Q1b) ‘How do the different intervention areas rank, in terms of how much of an impact can be expected from an intervention in the area?’.

For the topic of changeability, it is not possible to base the support on an explicative model that describes, in general, how and why future change affects buildings. Instead, the support will be based on an “*explorative model*” (see Klaasen, 2002, p. 184) describing how future change may affect a specific building, and why it is expected to work that way. For changeability, setting up this model is an essential part of the support. To develop comprehensive support for the topic of changeability, the following research questions must be answered: (Q2b) ‘How can potential problems of a building

design be identified, in relation to future change?'; (Q2c) 'How can design solutions to these potential problems be developed?'; and (Q2d) 'How can the relative importance of design solutions' inclusion in the building's design be determined, in relation to the building's changeability?'.

1.3.5. Descriptive study II

The fourth stage in a design research study is another descriptive study stage. The objective of this stage is to evaluate the design support that has been developed in the previous stage. There are two distinct aspects of design support that can be evaluated (Blessing and Chakrabarti, 2009, p. 37): (1) its application - can the support be used for the task for which it is intended; and (2) its success - does the support have the expected impact. Due to time constraints, the initial evaluation, of this method for evaluating a building's changeability, only focusses on the method's application. The goal of this stage is to answer the following research question: (Q2e) 'Can the evaluation method, that is presented in this study, be used to identify specific strengths and weaknesses of the building's design in relation to the user's changing requirements?'.

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1.4. Structure

Figure 1 shows how the topics of resource depletion, longevity and changeability are related to each other. In addition, Figure 1 shows the outcomes that are aimed for in this dissertation, per topic. The topic of resource depletion, and thus Q1a and Q1b, is dealt with in chapter 2: “*Resource depletion, where is an intervention most effective?*”. This chapter’s aim is comprehensive understanding and initial support, in relation to resource depletion. The topic of longevity, and thus Q1c, is dealt with in chapter 3: “*The evolution of ordinary houses, does it justify demolition?*”. This chapter’s aim is initial understanding, in relation to longevity. The topic of changeability, and thus Q2a, Q2b, Q2c, Q2d and Q2e, is dealt with in chapters 3 and 4: (3) “*How to set up criteria for evaluating a building’s changeability?*”; and (4) “*How adjustable is the Environmental Building?*”. Chapter 3’s aim is review-based understanding and comprehensive support, in relation to changeability. Chapter 4’s aim is initial evaluation, in relation to changeability. To summarize, this dissertation’s research goals are stated in the following research questions:

(Q-main) ‘How can a building design’s changeability, and the effect of this changeability on the problem of resource depletion, be evaluated?’;

(Q1) ‘How can the effect of a building design’s changeability on the problem of resource depletion be evaluated?’;

(Q1a) ‘What are the different intervention areas for the problem of resource depletion?’;

(Q1b) ‘How do the different intervention areas rank, in terms of how much of an impact can be expected from an intervention in the area?’;

(Q1c) ‘Is the evolution of buildings’ design a justifiable reason for a building’s demolition?’;

(Q2) ‘How can a building design’s changeability be evaluated?’;

(Q2a) ‘What are the types of design tactics used in design solutions of changeability?’;

(Q2b) ‘How can potential problems of a building design be identified, in relation to future change?’;

(Q2c) ‘How can design solutions to these potential problems be developed?’;

(Q2d) ‘How can the relative importance of design solutions’ inclusion in the building’s design be determined, in relation to the building’s changeability?’; and

(Q2e) ‘Can the evaluation method, that is presented in this study, be used to identify specific strengths and weaknesses of the building’s design in relation to the user’s changing requirements?’.

Chapter 2 is based on:

de Laat, P. (2019), “Resource depletion, where is an intervention most effective?”, *Smart and Sustainable Built Environment*, Vol. 8 No. 4, pp. 307-321.

CHAPTER

2

Resource depletion, where
is an intervention most
effective?

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Chapter 2's purpose

This study's societal end goal is to contribute towards mitigating the problem of resource depletion. Changeability has been selected as the means through which to pursue this goal. To understand the limitations of pursuing this goal through these means, it is necessary to understand the problem of resource depletion. Chapter 2's purpose is to develop both a comprehensive understanding of, and initial support for, the problem of resource depletion. In this study, changeability is not pursued for the sake of changeability. Changeability is pursued for the sake of mitigating the problem of resource depletion. Chapter 2's outcomes must guide this pursuit of changeability in the right direction.

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2.1. Introduction

Many authors have pointed out that the current usage of natural resources cannot be maintained forever (Boulding, 1966; Diederer, 2010; McDonough and Braungart, 2002; Meadows et al., 1972; Stahel, 1984). Some claim that society's standards are too high and that this is part of the problem (e.g. Diederer, 2010), while others deny that lower standards are necessary to resolve resource depletion (e.g. McDonough and Braungart, 2002). However, all agree that the take, make and dispose approach to achieving those standards is unsustainable. A substantial share of resource usage, and therefore the problem, is related to the construction sector (see Krausmann et al., 2009). According to Rittel and Webber (1973, p. 159), with such problems, known as "*wicked problems*", it is "*...less apparent where and how we should intervene even if we do happen to know what aims we seek*". Practitioners often use heuristics, i.e. rules of thumb, to make such decisions (see Persson and Ryals, 2014), because the available time to both search for information and make tough decisions are limited in real-world decisions.

A distinction can be made between two types of heuristics (rules of thumb): (1) rules that prioritize certain actions; and (2) rules that prioritize certain intervention areas. An example of the first type is the triad approach. It prescribes the following sequence of actions, ranging from most to least effective: (1) prevention of unnecessary use; (2) substitutional use; and (3) prudent conduct (see Entrop and Brouwers, 2010). An example of the second type is to prioritize energy efficiency during a building's daily operation over energy efficiency during its construction. In the first type of heuristics, one generalizes the impact of content, irrespective of its context. In the second type, one generalizes the role of context, irrespective of its content.

Rules of thumb can be very useful. However, many mistakes are made when practitioners rely on heuristics that they have developed informally themselves over time and based on their own experiences (see Tversky and Kahneman, 1974). Therefore, there is value in developing such heuristics in a more systematic manner. This chapter focuses on heuristics of the second type, i.e. rules that prioritize certain intervention areas. Of the two types, this type is arguably the least established within the field of construction.

2.2. Method

2.2.1. Introduction

This chapter's aim is to rank areas of the resource system, according to how much of a change can be expected from interventions in an area, in relation to the problem of depleting resources. In other words, where does one need to intervene in to be most effective? First, the areas are defined. After that, they are compared and ranked.

2.2.2. Define the areas

The resource system can be viewed in two ways: (1) as a process, i.e. a sequence of steps (e.g. Stahel, 1984); or (2) as a hierarchy, i.e. a cumulation of levels (e.g. Meadows, 1999). In this chapter, the process perspective has been adopted to define the intervention areas. To first define areas and afterwards rank them is only possible in this perspective. In the hierarchy perspective, the ranking of areas is the relation between them. The following principles of Structured Analysis (Ross, 1977) are used to create a process perspective of the resource system: (1) each model must have precisely one “viewpoint” and one “purpose”; (2) nothing which fits the purpose and viewpoint may be excluded; (3) each model must be composed of “things” and “happenings”; and (4) each model must be composed of neither too few nor too many pieces. Furthermore, Boulding (1966) noted that a perspective with too much emphasis on “throughput” may be part of the problem. Therefore, stocks have been added to the list of building blocks (things and happenings). The intervention areas will become clear from the resulting model.

2.2.3. Compare and rank the areas

According to Saaty (1990, p. 12), “*the most effective way to concentrate judgement is to take a pair of elements and compare them on a single property without concern for other properties*”. When this has been done for all elements and all properties, the results are added together. This is termed the Analytic Hierarchy Process. The effectiveness of intervening in an area is determined by the following two properties: (1) how much there is to be gained in an area; and (2) how much an intervention in an area is expected to snowball, i.e. to cause a snowball effect.

The first property, i.e. how much there is to be gained in an area, is composed of both: (a) the initial amount and (b) its previous exploitation, i.e. how much of that amount has already been exploited. Hayek (1967, pp. 96-105) used the term “*human action*” to describe something that happened without purposeful human design but not without

human influence. The initial amount is a result of human action, while the previous exploitation is a result of purposeful human design.

This distinction is useful because an area's previous exploitation indicates how effective future exploitations of that area will be. In economics, there is a rule of thumb named "*the law of diminishing returns*" (Oxford Dictionary of Economics, 2012). It states that a continuing application of effort toward a particular goal will decline in effectiveness after a certain level of result has been achieved (see von Bertalanffy, 1968, pp. 60-63). In other words, when an area has already been substantially exploited, future interventions will be increasingly less effective.

The second property, i.e. how much an intervention in an area is expected to snowball, also comprises two parts: (a) the connectedness between areas; and (b) the range of potential interventions. Firstly, when an area is closely connected to other areas, a change in that area will ripple through the areas directly next to it. This ripple effect will not happen in an isolated area. Thus, more of a snowball effect is expected in more connected areas. Secondly, only certain interventions are possible within each area. Some interventions cause more of a snowball effect than others. Thus, when such interventions are not possible within an area, less of a snowball effect can be caused there. However, more of an effect is expected from interventions in areas where the less effective interventions are not possible.

Table 1 shows how the intervention areas will be compared. First, the areas are scored (between 1 and 5) on each sub-property. These scores are all relative. They are based on answers for the following type of question: why is area [x] better/worse in property [y] than others? Each score is then multiplied by a weighting factor (1/3rd or 1/6th), because two of the properties are more important than the others. The final score is calculated by adding the weighted scores together.

intervention areas	scores on (1a) initial amount	scores on (1b) previous exploitation	scores on (2a) connectedness between areas	scores on (2b) range of p. interventions	final scores
area 1	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	...
area 2	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	...
area 3	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	score · (1/3) + score · (1/6)	...

Table 1. How the intervention areas will be compared.

2.3. Results

2.3.1. A process perspective

2.3.1.1. Introduction

Figure 2 shows the process of using resources. A grey box represents a stock and a white box represents an activity. The symbols (-) and (+) show when things are subtracted from or added to a stock, respectively, while the symbols (- -) and (+ +) show when something is consumed or generated, respectively. Furthermore, the symbols (») and («) show when products' lifespans are unfavourably or favourably affected, respectively.

2.3.1.2. Viewpoint and purpose

The “*viewpoint*” is the topic of a Structured Analysis (Ross, 1977, p. 18), in this case: resource usage. The “*purpose*” determines the importance of things and happenings in the systemization (Ross, 1977, p. 18). It determines what is and what is not to be included from the viewpoint. The purpose of this model: to optimize resource effectiveness in the interests of the collective, i.e. humankind.

Owning or having access to certain amounts of particular products is a universal preference. Through the use of such products, people attain something intangible which is termed material well-being. Material well-being is seen as a condition of the psyche (see Boulding, 1966, pp. 8-10) which lessens overtime and is supplemented through the use of products. In other words, material well-being is a stock which regularly needs to be replenished. The optimum level of material well-being which should be strived for - and its distribution amongst society - is beyond the scope of this chapter. However, maximizing the level of material well-being that can be sustained provides the most suitable boundary conditions for addressing resource allocation.

2.3.1.3. Phases

A distinction can be made between two phases: the manufacturing phase and the operation phase. Eekhout (1997, pp. 27-33) describes the process of manufacturing building products in six steps: (1) raw materials are purified to mono materials; (2) mono materials are mixed to form composites; (3) composites are shaped to materials of commerce; (4) materials of commerce are adapted to elements; (5) elements are assembled into components; and (6) components are assembled into products. This sequence of steps is universally applicable, though not all manufacturing processes go through all of the steps. Each process always starts with a resource. Thus, before any of these six steps can happen, resources need to be extracted (step 0). Also, all products

Figure 2. The process of using resources. A grey box represents a stock and a white box represents an activity. The symbols (-) and (+) show when things are subtracted from or added to a stock, respectively, while the symbols (- -) and (+ +) show when something is consumed or generated, respectively. Furthermore, the symbols (>>) and (<<) show when products' lifespans are unfavourably or favourably affected, respectively.

are made for a purpose. After all the other steps have been completed, the product is handed over (step 7). In the construction sector, this generally means that the product is placed or installed at a specific location.

When a product is handed over, this conventionally means that its ownership is also handed over. The operation phase is associated with the concept of ownership. The operation phase begins when the product is handed over to a consumer. It ends when this ownership ends. Ownership can end in two ways: (1) a party willingly takes over the product; or (2) it is disposed of. In the first situation, the product's removal is the first step of the manufacturing phase, i.e. the extraction of a resource. In the second situation, the product's disposal is the final step of the operation phase. Afterwards, if the product is salvaged from the place it was dumped at, this salvaging action is the first step of a new manufacturing phase.

Furthermore, products' longevity is closely associated with the phases. Though it cannot be referred to as a phase itself, products' longevity does determine the relative importance of the manufacturing phase versus the operation phase. With longer lifespans, the operation phases become longer. Therefore, products do not need to be remanufactured as often.

2.3.1.4. Material inputs

Materials can be classified as either organic or inorganic (Czichos, 2006). Organic materials can then be classified as materials that quickly renew (grow back) or materials that require a long time to renew. This distinction is useful because even crude oil is organic in origin (see Oxford Dictionary of Chemical Engineering, 2014), despite the fact that almost no oil 'grows back' in a generation's lifetime because its renewal rate is so low.

Material inputs are presented (in Figure 2) as something which is only redistributed and reconfigured. There are two exceptions: (1) the renewal and decay of organic resources; and (2) the incineration of organic resources to generate energy. Other than that, there is no way for resources to enter or leave the system. This may seem somewhat counter-intuitive in relation to the concept of waste. However, waste is not a physical loss of resources, but a loss in value. Since people extract materials from their natural settings rather than from disposed and valueless products, it must be easier and cheaper to exploit virgin resources. In other words, due to the initial manufacturing process, materials have become less suitable for future manufacturing processes.

For energy, the concept of exergy, which describes the usefulness of energy states (Rant, 1956), was introduced to describe such a loss of usefulness. A similar concept

can be used to describe the usefulness of material states, as matter and energy are alike in the fact that it is more troublesome to concentrate diffused particles than it is to diffuse concentrated ones (see Diederer, 2010, p. 8). In Figure 2, both material losses in manufacturing and discarded products & parts in operation are categorized as resources. They both only differ from virgin resources in terms of material states.

2.3.1.5. Process inputs

All products do not contribute in the same way to material well-being. A distinction is made between products that contribute directly and those that contribute indirectly to material well-being. For example, a pair of trousers fulfils a clear purpose; a person benefits directly from wearing it. Such a product is referred to as a purpose product. A washing machine, on the other hand, makes it easier to maintain products such as a pair of trousers. People do not benefit from a washing machine in and of itself. However, it improves the ease of use of other products greatly. Such a product is referred to as a supporting product. This distinction is useful because products that have a more direct link to material well-being are harder to change without affecting their contribution to material well-being.

In Figure 2, the relation between purpose products and supporting products is shown as follows: (1) supporting products produce process inputs; and (2) the consumption of such inputs represents the use of such products. This is similar to how a lay person, i.e. a non-physicist, describes energy: a source that is generated and consumed. For supporting products, this description makes sense from the perspective of products' technical lifespan (see Gijsbers, 2011, pp. 21-23). All products undergo wear and tear that will eventually break them down.

From this perspective, a screwdriver does not differ from a solar panel. Both are made to provide a certain supporting service. For the solar panel, this service is generating energy. For the screwdriver, this service is tightening and loosening screws. A solar panel is limited in the amount of energy it can generate in its lifetime, because all products only remain functional for a limited time. Similarly, a screwdriver is limited in the amount of times it can be used. A process input represents a supporting product's functional contribution. This can thus be an amount of energy, but also the application of a product.

2.3.1.6. Intervention areas

From the model, five intervention areas are defined. These areas are listed in Table 2. An area is defined by two focusses. Each area focusses on either (a) the manufacturing

phase or (b) the operation phase, and within that scope, each area focusses on (a) material inputs or (b) process inputs. However, the fifth area is an exception. It does not focus on one of the phases, but instead it focusses on the longevity of products. Products' longevity determines the relative importance of the manufacturing phase versus the operation phase. With longer lifespans, the operation phases become longer. Therefore, products do not need to be remanufactured as often. The manufacturing process consumes process inputs (see Figure 2). So, when products do not need to be remanufactured as often, fewer process inputs are required for manufacturing. This is the numerical effect of an intervention in products' longevity.

Nonetheless, the effects of such interventions are mostly visible during the operation phase. Buildings last longer when it is easy to modify them and when it is easy to use them differently. Both these activities are related to the operation phase. When a building is adaptable, it is easily modified. Therefore, when a part of such a building needs to be updated, it is easier to make space for the update. This implies a numerical effect on the process inputs to the operation phase. However, in a non-adaptable building, such an update will often be too costly. Instead, updates are postponed until the entire building is replaced, which would happen a lot sooner without updates. So, despite the fact that an intervention in products' longevity mostly changes how the operation phase works, it mostly has a numerical effect on the manufacturing phase. Neither of the two phases completely cover the effects of an intervention in products' longevity. Therefore, products' longevity is set apart as a separate area.

no.	description	code
1	(a) material inputs (a) to manufacturing	a.a.
2	(b) process inputs (a) to manufacturing	b.a.
3	(a) material inputs (b) to operations	a.b.
4	(b) process inputs (b) to operations	b.b.
5	(c) products' longevity	c.

Table 2. The five intervention areas.

2.3.2. Ranking

2.3.2.1. Introduction

In this section, all areas are ranked, i.e. put in a sequence from best to worst. A separate ranking is made for each of the following sub-properties: (1) initial amount; (2) previous exploitation; (3) connectedness between areas; and (4) range of potential interventions.

Each area is given a score of between 1 and 5 based on its position in a ranking. Priority is given to providing a complete picture. So, some reasons behind a ranking will be better than others. Markings are used to clarify the author's thoughts about the validity of an area's rank. Each time a rank is assigned, it is marked with either two asterisks (**), one asterisk (*) or no asterisks (-). The number of asterisks symbolizes the author's confidence in the ranking, in which more asterisks signifies more confidence (this marking system is adopted from Alexander et al., 1977, pp. xiv-xv).

2.3.2.2. Initial amount

Table 3 shows how the five areas are ranked according to how much there initially was to be gained in an area. There are three reasons behind this ranking. Reason #1: a shortage of materials is not different from a shortage of process inputs. A distinction can be made between "*resource reserves*" and the "*resource base*" (Ashby, 2012, pp. 32-33). The resource base represents all resources that exist on this planet. The resource reserves represent a share of the resource base. It includes all resources that can be accessed using today's technology for a reasonable price. Many authors (e.g. Allwood et al., 2011; Boulding, 1966; Diederer, 2010; Meadows et al., 1972) seem to believe that depleting resources does not mean that the base is running out of resources, but that the reserves are depleting.

When the reserves of a specific resource are running out, there are two options: (1) to not use the material anymore, because it has become too costly to extract; or (2) to reserve a greater share of all process inputs for its extraction, because the resource cannot be missed. A lack of a specific material can thus be compensated for by allocating more process inputs. On the other hand, insufficient process inputs makes the extraction of materials more difficult. A shortage of materials and a shortage of process inputs cannot be isolated from one another; they represent the same problem.

Reason #2: more can be gained in operations than in manufacturing. Of the two, the operation phase is the most significant phase, because buildings and building products last a long time. For example, the exterior of a building changes "*every 20 years or so*", and its installations "*wear out or obsolesce every 7 to 15 years*" (Brand, 1994, p. 13). Also, a house lasts on average about 30 years in Japan, 55 years in the United States and 77 years in the United Kingdom (Eguchi et al., 2011, p. 74, Figure 1).

The time that a house is used can be more than 50 times as long as the time it takes to construct it (e.g. 9 months of construction and 50 years of use). During that time, a building requires a lot of energy, for example for heating and lighting; "*it has been confirmed [by several studies] that operation energy is by far the most important*

contributor to life cycle impacts of conventional buildings” (Blengini and Di Carlo, 2010, p. 869).

Furthermore, not all materials pass through the manufacturing phase before they go into the operation phase: a substantial share of all extracted resources are immediately combusted to generate energy (see Krausmann et al., 2009). The operation phase involves more materials, than the manufacturing phase, in this regard. However, a similar claim can also be made for manufacturing: not all materials that are processed in the manufacturing phase end up in the final products. For example, Hicks et al. (2004, p. 170) studied a manufacturing process in which (about) 23% of incoming materials were wasted by the end of the process. This is referred to as yield loss (Allwood et al., 2011, p. 365).

Reason #3: products’ longevity and the manufacturing phase are also significant intervention areas. Seeing how the average lifespan of houses varies across different cultures, each with their own construction methods, gives some idea about how much longevity can be gained by a good design, a suitable financial model and a suitable construction process. However, research mostly highlights the importance of the operation phase. Little information points towards the potential of the manufacturing phase or products’ longevity. Therefore, these areas are given a neutral score (3).

rank	area	score	validity
1	material inputs to operations (a.b)	5	* *
	process inputs to operations (b.b)	5	* *
2	products’ longevity (c)	3	-
	material inputs to manufacturing (a.a)	3	*
	process inputs to manufacturing (b.a)	3	*

Table 3. The ranking of intervention areas in terms of the initial amount. A score of 5, 3 or 1 means that an area scores best, neutral or worst, respectively, on this sub-property. A validity of 2, 1 or 0 asterisks means that the author is most, averagely or least confident, respectively, in the validity of the ranking.

2.3.2.3. Previous exploitation

Table 4 shows how the five areas are ranked according to how little of an area has already been exploited. There are three reasons behind this ranking. Reason #1: operation energy has been a very popular intervention area. For example, the European Parliament’s energy directive (2010) mandates that future buildings have to be built as “*nearly zero-energy buildings*”. It is no wonder that “...*especially for new and low*

energy buildings, the relative role and the importance of life cycle phases are changing” (Blengini and Di Carlo, 2010, p. 869). However, only 0.25% of old houses are replaced annually in the Netherlands (Thomsen and van der Flier, 2009, p. 653). Thus, it will take quite some time before all houses are nearly zero-energy buildings.

Reason #2: the manufacturing phase has not received the same amount of attention as operation energy. The manufacturing phase has received some attention. For example, yield losses in Sweden have been halved in eight years (Shahbazi et al., 2016). This attention just has not been at the same level as the attention to reducing operation energy.

Reason #3: of the five areas, products’ longevity has received the least attention. Instead of improving, buildings’ longevity may very well be decreasing over time. In Zurich (Switzerland) for example, buildings do not even last half as long as they used to (Aksözen et al., 2017, p. 254, Fig. 10). A similar trend can be seen for consumer products. For example, the expected lifespan of personal computers has almost been halved in fifteen years (Babbitt et al., 2009). This intervention area may have received less attention than the others, because the threshold is higher for intervening in longevity – such interventions are not straightforward.

rank	area	score	validity
1	products’ longevity (c)	5	*
2	material inputs to manufacturing (a.a)	3	-
	process inputs to manufacturing (b.a)	3	*
	material inputs to operations (a.b)	3	*
3	process inputs to operations (b.b)	2	* *

Table 4. The ranking of intervention areas in terms of the previous exploitation. A score of 5, 3 or 1 means that an area scores best, neutral or worst, respectively, on this sub-property. A validity of 2, 1 or 0 asterisks means that the author is most, averagely or least confident, respectively, in the validity of the ranking.

2.3.2.4. Connectedness between areas

Figure 3 shows how an intervention in one area affects the others. In Figure 3, a number 1 is placed in all cells across the diagonal. A number 1 represents the focus area, i.e. the area that people try to change through an intervention. Next, horizontal arrows start from number 1 cells and end up in number 2 cells. These arrows represent ripple effects. An intervention’s effect on a number 1 cell ripples through the number 2 cells

Figure 3. How an intervention in one area affects the others. A number 1 cell represents the focus area. The horizontal arrows represent a ripple effect. An intervention's effect on a number 1 cell ripples through the number 2 cells within the same row. How this effect ripples further is made clear by the vertical arrows. For every number 2 cell, a vertical arrow points towards the row that describes its further progress.

within the same row. After that, the effect on a number 2 cell ripples further (although, the effect becomes increasingly less). How this effect ripples further is made clear by the vertical arrows. For every number 2 cell, a vertical arrow points towards the row that describes its further progress.

The first row of Figure 3 describes the following: when less material goes into the manufacturing process, fewer process inputs are required (assuming a constant requirement per processed quantity of material). The third row describes something similar: when fewer products are used, fewer process inputs are required. For example, each product requires some maintenance. Thus, when people have more products, they have more things to maintain. However, the third row also describes a situation in which fewer products are used and, therefore, fewer products need to be made. This affects the material inputs to manufacturing. However, this does not hold true for the other way around; less material can be used in manufacturing without making fewer products (e.g. by making lighter products).

The second and fourth rows of Figure 3 describe the following: when fewer process inputs are required, fewer supporting products are needed to generate such inputs, and fewer inputs will be combusted for generating energy, i.e. two times a reduction of material inputs to the operation phase. An intervention in the inputs that are combusted for generating energy is the only type of intervention that does not have a further effect on any of the other areas.

In summation: (1) an intervention in the material inputs to operations indirectly affects two other areas; (2) an intervention in the process inputs affects one other area in two different ways, and only one of those ways has a further effect on another area; and (3) an intervention in the material inputs to manufacturing only affects one other area. Table 5 shows how the five areas are ranked according to how connected an area is to other areas. Products' longevity is scored the same as the process inputs to the manufacturing phase, because an intervention in longevity only has a numerical effect on this area (see 3.1.6.).

rank	area	score	validity
1	material inputs to operations (a.b)	5	* *
2	products' longevity (c)	3	-
	process inputs to operations (b.b)	3	*
	process inputs to manufacturing (b.a)	3	*
3	material inputs to manufacturing (a.a)	2	*

Table 5. The ranking of intervention areas in terms of the connectedness between areas. A score of 5, 3 or 1 means that an area scores best, neutral or worst, respectively, on this sub-property. A validity of 2, 1 or 0 asterisks means that the author is most, averagely or least confident, respectively, in the validity of the ranking.

2.3.2.5. Range of potential interventions

Table 6 shows how the five areas are ranked in terms of their range of potential interventions. The reasons behind this ranking are as follows: (1) all potential interventions in products' longevity cause a considerable snowball effect; (2) none of the potential interventions in manufacturing cause much of a snowball effect; and (3) of the potential interventions in operations, some do and some do not cause a considerable snowball effect.

According to Meadows (1999), one of the greatest snowball effects is achieved by changing the “rules” of a system. On the other hand, changing the “parameters” of a system does not cause much of a snowball effect. The parameters of a system include everything that can be described by a number. For example, the number of elements is a parameter, but also the strength of a relation between two elements. The rules of a system describe where the relations between elements are placed and how they work (cf. Meadows, 1999, pp. 5-7; von Bertalanffy, 1968, pp. 54-55). Table 7 lists 14 interventions in resource usage that have been mentioned by other authors. For each of

these interventions, Table 7 shows the following: (1) the intervention area; and (2) the intervention level, i.e. whether the intervention affects the system's parameters or the system's rules.

Light-weighting, i.e. making products that contain less material, is an example of an intervention in the system's parameters. Such an intervention changes the product, but it does not change how the product is handled and, therefore, it does not cause much of a snowball effect. Selling things on a performance based lease (see Stahel, 2010) is an example of an intervention in the system's rules. Normally a person buys a product and becomes its owner. Then, if the product is not working as it should be, or if it is not as efficient as it should be, a person can complain and, the next time, he or she can buy a different product. However, when the manufacturer remains responsible for the performance of the product, the situation will be different. For example, when the product wastes energy, the owner has to pay for that. When the manufacturer is the owner, they will be stimulated to improve on such aspects of their product. This changes how the product is handled and, therefore, it causes a considerable snowball effect.

In Table 7, four interventions are categorized as the type parameters/rules. This means that these interventions are harder to put in one of the two categories. For example, there are two ways to interpret remanufacturing and component re-use: (1) as new relations, i.e. material flows that previously did not exist; or (2) as a strengthened relations, i.e. more product and parts are re-used and remanufactured than they used to be. For this ranking, these four borderline cases are put in the same category as other interventions associated with the same area. Thus, remanufacturing and component re-use affect a system's parameters, while physical durability and reliability affect a system's rules.

rank	area	score	validity
1	products' longevity (c)	4	*
2	material inputs to operations (a.b)	3	*
	process inputs to operations (b.b)	3	* *
3	process inputs to manufacturing (b.a)	2	-
	material inputs to manufacturing (a.a)	2	*

Table 6. The ranking of intervention areas in terms of the range of potential interventions. A score of 5, 3 or 1 means that an area scores best, neutral or worst, respectively, on this sub-property. A validity of 2, 1 or 0 asterisks means that the author is most, averagely or least confident, respectively, in the validity of the ranking.

source	intervention	area	level
Allwood et al., 2011	increased recycling rates	p. inputs to manufacturing	parameters
Allwood et al., 2011	yield improvement	m. inputs to manufacturing	parameters
Allwood et al., 2011	more intense use	m. inputs to operations	rules
Allwood et al., 2011	remanufacturing	p. inputs to manufacturing	parameters/rules
Allwood et al., 2011	component re-use	p. inputs to manufacturing	parameters/rules
Allwood et al., 2011	light-weighting	m. inputs to manufacturing	parameters
Stahel, 2010	performance based leasing	p. inputs to operations	rules
Bocken et al., 2016	emotional durability	products' longevity	rules
Bocken et al., 2016	physical durability	products' longevity	parameters/rules
Bocken et al., 2016	reliability	products' longevity	parameters/rules
Bocken et al., 2016	ease of maintenance and repair	products' longevity	rules
Bocken et al., 2016	upgradability and adaptability	products' longevity	rules
Bocken et al., 2016	standardization and compatibility	products' longevity	rules
Bocken et al., 2016	dis- and reassembly	products' longevity	rules

Table 7. Interventions in resource usage mentioned by other authors. They are categorized in both intervention area and intervention level, i.e. whether the intervention affects the system's parameters or the system's rules.

2.3.2.6. Final ranking

Table 8 shows the final ranking. Each area has been given a score for each determining sub-property. The final score is calculated by multiplying each score by a weighting factor and by then adding the weighted scores together. The highest rank is given to the highest score.

intervention areas	scores on (1a) initial amount	scores on (1b) previous exploitation	scores on (2a) connectedness between areas	scores on (2b) range of p. interventions	final scores
a) material inputs b) to operations	$5 \cdot (1/3)$	$3 \cdot (1/6)$	$5 \cdot (1/3)$	$3 \cdot (1/6)$	$4 \frac{1}{3}$
b) process inputs b) to operations	$5 \cdot (1/3)$	$2 \cdot (1/6)$	$3 \cdot (1/3)$	$3 \cdot (1/6)$	$3 \frac{1}{2}$
c) products' longevity	$3 \cdot (1/3)$	$5 \cdot (1/6)$	$3 \cdot (1/3)$	$4 \cdot (1/6)$	$3 \frac{1}{2}$
b) process inputs a) to manufacturing	$3 \cdot (1/3)$	$3 \cdot (1/6)$	$3 \cdot (1/3)$	$2 \cdot (1/6)$	$2 \frac{5}{6}$
a) material inputs a) to manufacturing	$3 \cdot (1/3)$	$3 \cdot (1/6)$	$2 \cdot (1/3)$	$2 \cdot (1/6)$	$2 \frac{1}{2}$

Table 8. The final ranking. The final score is calculated by multiplying each score by a weighting factor and by then adding the weighted scores together.

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2.4. Discussion and conclusion

2.4.1. Discussion

In the Introduction, two types of heuristics were mentioned: (1) rules that prioritize certain actions; and (2) rules that prioritize certain intervention areas. The first type is easier to use; a person just does the action that is prescribed. For the second type, there are two options. Option 1: a person picks the intervention area that is prescribed, and comes up with an action that focusses on that particular area. Option 2: for each action that a person is considering, he or she thinks of the intervention area that it focusses on. That person then picks the action that focusses on the most important intervention area. To use heuristics of the second type, a good understanding is required of how actions affect the system. In this case, a good understanding is required of Figure 2. That makes it harder for decision makers to use such rules of thumb. However, when they do invest the time that is needed to learn how to use such heuristics, they will be more aware of what they are using. As a result, decision makers will make fewer mistakes; they will not use generalizations when they are not applicable. By following rules of thumb that prescribe actions, on the other hand, it is easy to oversimplify matters.

In this chapter, priority was given to providing a complete picture. Therefore, further improvements are necessary, especially in the individual sub-scores. The asterisks show which rankings are the least certain and thus require additional work the most. The Analytic Hierarchy Process makes explicit how the final ranking is composed. Therefore, it is easy to add to or improve the current reasoning.

2.4.2. Conclusion

This chapter's aim was to determine where one needs to intervene to be most effective. The answer is that one must prioritize intervention areas as follows: (1) material inputs to the operation phase; (2) process inputs to the operation phase and products' longevity; (4) process inputs to the manufacturing phase; and (5) material inputs to the manufacturing phase.

These results are generalizations, expressed as rules of thumb, and relying on rules of thumb is always risky. However, most decision are not made on the basis of rigorous analysis. These rules of thumb can help decision makers prioritize what is most important. When that happens, they will be one step closer to solving the problem of depleting resources.

Chapter 3 was made in collaboration with Pieter R. Beurskens. The author of this dissertation wrote the final text, but earlier versions were written together. Data was also gathered and analysed together. Pieter has read the final version, and he gave permission to include this version in this dissertation.

CHAPTER

3

The evolution of ordinary
houses, does it justify
demolition?

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Chapter 3's purpose

Longevity is the link between the topics of changeability and resource depletion. Thus, in order for changeability to have an effect on resource depletion, change must have an effect on longevity. Furthermore, within this effect that change has on longevity, design must matter. When a building's physical qualities are not taken into account in the decision-making process of the building's demolition, there is no point in improving a building's design in relation to future change. Chapter 3's purpose is to develop an initial understanding of the role of a building's physical qualities within the decision-making process of the building's demolition. Chapter 3's outcome must provide a first indication of to what extent a building's longevity is determined by its design. This knowledge will contribute to a more valid assessment of changeability's contribution towards mitigating the problem of resource depletion.

3.1. Introduction

A house plays a central role in a person's life. More than half of a person's time is spent at home (Schweizer et al., 2006). In the Netherlands, annual investments in houses are twice as high as the combined annual investments in all other buildings (Soeter, 2010, p. 2). On the one hand, developments in housing supply and demand indicate that houses must last hundreds of years (Meikle and Connaughton, 1994; Soeter, 2010, pp. 93-96). On the other hand, the average age of demolished buildings is not so high (see Huuhka and Lahdensivu, 2016, p. 87, Table 10; O'Connor, 2004, p. 6, Fig. 3), and may even be decreasing (see Aksözen et al., 2017, p. 254, Fig. 10).

The ordinary house is changing. Today's houses are not the same as houses from 100 years ago, and future houses will also differ from today's houses. Buildings are often demolished to make room for new buildings (Huuhka and Lahdensivu, 2016, p. 89, Table 12). Furthermore, people often say that a building needed to be demolished because it was "*no longer suitable for [its] intended use*" (O'Connor, 2004, p. 8, Fig. 7). However, according to Thomsen (2006, p. 21), social houses' demolition often has little to do with their physical qualities, instead various social factors mainly determine whether they are demolished or not.

This chapter's aim is to determine how the ordinary house, in the Netherlands, has changed throughout the last 100 years. This chapter focusses on both the spatial characteristics and the technical characteristics of houses. This information will be used to discuss: to what extent the house's evolution justifies demolition.

In the Netherlands, a lot of studies have already been done on housing (Bruggeman, 1981; Hasselaar, 2001; Liebrechts and van Nunen, 2014; Prak, 1991; Priemus and van Elk, 1970; Thijssen 1999; Thijssen and Meijer, 1988; Vreeze, 2001). However, none of these studies completely fulfil this chapter's purpose. Half of them only focus on houses built in the 20 years after the Second World War (Bruggeman, 1981; Priemus and van Elk, 1970; Thijssen 1999; Thijssen and Meijer, 1988). Prak (1991) focused on an earlier time period (1800-1940), and Hasselaar's study (2001) focused only on the health and indoor climate aspects of buildings. In the two studies (Liebrechts and van Nunen, 2014; Vreeze, 2001) that did cover a large enough part of recent history (100 years), it is unclear where their findings are based on. Therefore, this additional research is necessary.

In this chapter, 68 building projects are analysed. For this analysis, the documents included in building permit applications are used. These documents show how a building was originally constructed. Nijmegen is about the only city in the Netherlands with a

completely digitalized building archive, that is publicly available online. Therefore, all selected projects are from Nijmegen. Previous studies did not focus on a single city. Therefore, whenever possible, this chapter's results are compared to the results of those previous studies.

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3.2. Method

3.2.1. Introduction

A non-random sampling method is used to select the 68 cases. It is especially important, with such a method, to describe how cases are selected, how the data is collected and what the conclusions are based on (Baker et al., 2013, pp. 106-107). Without such transparency, it is impossible to judge how generally applicable the conclusions are. In the Method (3.2.) is described how cases are selected. In the Results (3.3.) is explained how the actual data is collected and what the conclusions are based on.

Four selection criteria are used: (1) type of residential building; (2) project size; (3) construction year; and (4) location. The first and second criteria must make sure that only ordinary houses are selected. These criteria are based on the “*typicalness criterion*” (Bull, 2005, p. 168). The third and fourth criteria must make sure that no type of ordinary house is excluded. These selection criteria are based on the “*distinctness criterion*” (Bull, 2005, p. 167).

3.2.2. Type of residential building

The type of residential building is determined by three characteristics: (1) type of entrance; (2) type of stack; and (3) type of row. The type of entrance refers to how a housing unit is entered. Option 1: the front door is directly connected to the public space. Option 2: the circulation space, directly in front of the front door, is intended for two housing units. Option 3: the circulation space, directly in front of the front door, is intended for more than two housing units.

The type of stack refers to how housing units are stacked on top of one another. A housing unit can be not part of a stack. Otherwise, a housing unit can be part of a stack of two, or a housing unit can be part of a stack of more than two. The type of row refers to how housing units are put in a row. A housing unit can be not part of a row. Otherwise, a housing unit can be part of a row of two, or a housing unit can be part of a row of more than two.

Figure 4 shows how the types of residential building are specified by different combinations of the options under each of these three characteristics. The following types are specified: freestanding house; double house; row house; two-family house; and block of flats. Block of flats is a broad term. Figure 4 shows the four different combinations, from the sample, that are referred to as a block of flats. Freestanding houses, double houses and row houses are all single-family houses. Two-family houses and blocks of flats are referred to as multiple-family houses.

Figure 4. How the types of residential building are specified by different combinations of the options under each of the three characteristics, i.e. (1) type of entrance; (2) type of stack; and (3) type of row.

There is one exception to Figure 4. Some houses, that are in a row, are not referred to as row houses. These houses are known as “linked” houses. Two common examples are the “linked freestanding house” and the “linked double house” (see NVM et al., 2013). Row houses have a large part of their main-volume ($\geq 50\%$) directly next to each other. A weaker connection is referred to as a link.

Table 9 shows how common each type of residential building is in the Netherlands. These numbers are based on the “WoON12 dataset” (BZK & CBS, 2013). In that study, almost 70.000 respondents filled in the type of building they live in. The row house is the most common type (41%), in the Netherlands. The block of flats is the second most common type (20%). The row house is a single-family house, and the block of flats is a multiple-family housing building. However, the block of flats is a relatively new

type; high-rise buildings were introduced quite late in the Netherlands (Prak, 1991, p. 179; Wagenaar, 1992). Therefore, the two-family house (8%) is added to the scope. As a result, the evolution of both single-family houses and multiple-family houses is included in the chapter.

Furthermore, three linked double houses are included in the sample. In Nijmegen, a lot of the houses, built between 1990 and 2000, are linked double houses. These three exceptions are included because they match best with the other selection criteria (project size, construction year and location).

single-family housing	69,5 %	multiple-family housing	30,6 %
freestanding houses	14,0 %	two-family houses	8,4 %
double houses	12,3 %	blocks of flats	20,0 %
row houses	41,0 %	others	2,2 %
others	2,2 %		

Table 9. How common is each type of residential building in the Netherlands (percentages based on the WoON12 dataset).

3.2.3. Project size

Usually, a construction project involves more than one housing unit. However, most single-family houses were built in small projects (Prak, 1991, p. 4; Thijssen, 1999, p. 1). On the other hand, by including large projects the sample quickly becomes larger. Therefore, large projects are preferred. In the earlier time periods, it is not always possible to select large projects. They were not as common. The smallest project that is selected includes 5 housing units, while the largest includes 468 units. On average, a project includes about 122 housing units. In total, 8270 housing units are included, which is about 10% of all housing units in Nijmegen (based on data from the central agency for statistics (CBS) in the Netherlands).

Only one unit per project is actually analysed. Often, a housing unit is marked in the architect's drawings as a standard unit. Otherwise, it is up to the researchers to select the most common one. The two-family houses are treated a bit differently. They include two standard units, i.e. a downstairs unit and an upstairs unit. Both of them are analysed.

3.2.4. Construction year

This chapter's focus is the period from 1900 to 2012. About 90% (based on data from the CBS of 2018) of today's buildings were built in this time period. Key moments are used to divide the period into parts. From each part, about four single-family projects

and four multiple-family projects are analysed. A key moment is an event in time after which new construction projects, probably, had become different from what they used to be. Figure 5 shows how the timeline is divided into parts.

The three most significant key moments for the construction industry were the Second World War ('39-'45), the oil crisis ('73-'74) and the introduction of the Dutch Building Code ('92). Other important years are 1920, 1930, 1960 and 2003. The updated building code was introduced in 2003. New regulations have a significant impact on the construction industry; over 30% of all innovations, in this sector, are the result of new regulations (Pries & Dorée, 2005). In 1920, the cavity wall was introduced in the Netherlands (Rentier et al., 2005, p. 18). However, it took until 1930 for it to become a widespread practice (Archidat & Bouwinformatie, 2012, p. 9). Lastly, 1960 is referred to as a “*turning point*” in the post-war period (Pries, 1995, pp. 93-95). Around this time, some flaws in the way houses were rebuild had become clear and, from then on, people started working towards better results.

Figure 5. How key moments are used to divide the timeline into 8 parts.

3.2.5. Location

Figure 6 shows a map on which all selected cases are marked black. The smaller projects are, unfortunately, hard to see due to the small size of the map. However, each case’s specific information is included in Appendix 1. The projects are spread out as much as possible. This was not always possible, because the city has a history of planned expansions (Ekkers & Ganzevles, 2005).

Figure 6. A map of Nijmegen with the locations of all selected cases marked black.

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3.3. Results

3.3.1. Introduction

Figure 7 shows a timeline on which all 68 cases have been placed. In Figure 7, the single-family cases (#1-#37) are shown directly above the timeline, and the multiple-family cases (#38-#68) are shown directly below the timeline. The place on the timeline shows a case's construction year. For example, in Figure 7, case #9 is placed at 1930, this means that case #9 was built in 1930. The following figures present results in a similar way: Figure 8; Figure 9; Figure 10; Figure 11; Figure 12; Figure 14; Figure 15; Figure 16; Figure 18; Figure 19; Figure 20; Figure 21; Figure 22; Figure 23; Figure 24; and Figure 25. However, in these figures, categories are placed on the timeline, instead of case numbers. For example, when category A's symbol is placed at 1930, this means that a case, that was built in 1930, is classified under category A. This way of presenting data shows how a building characteristic has evolved throughout the timeline. Specific information about the cases is included in Appendix 1.

Figure 7. Each case's number on the timeline. Single-family cases (#1-#37) are shown above the line, and multiple-family cases (#38-#68) are shown below the line.

3.3.2. Spatial characteristics

3.3.2.1. Length and width

Figure 8 and Figure 9 show how the sample is categorized in terms of length and width, respectively. These figures show measurements of buildings' main volumes. Both the length and width were obtained by measuring the distance between one wall's inner face and another wall's inner face. Three conclusions can be drawn from these figures. Conclusion #1: since 1990, houses have become deeper. Between 1900 and 1990, a single-family house's length was on average 7,8 meters. Between 1990 and 2012, a single-family house's length was on average 9,5 meters. Similarly, a multiple-family house's average length has increased from 9,0 to 12,5 meters, in around 1990.

Conclusion #2: houses' footprints were squarest between 1945 and 1970. Single-family houses from between 1945 and 1970 had, on average, a length-to-width ratio of 1 : 1,25. Similarly, multiple-family houses from that period had, on average, a length-to-width ratio of 1 : 1,30. Throughout the rest of the timeline, single-family houses' average length-to-width ratio is 1 : 1,67, and multiple-family houses' average length-to-width ratio is 1 : 1,54. Conclusion #3: the width of single-family houses has been quite consistent throughout the time period. More than 70% of all single-family houses, in the sample, have a width of between 5 and 6 meters. The largest width in the sample is 6,3 meters, and the smallest width in the sample is 4,5 meters.

Figure 8. Each case's length on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: < 7.5 meters; between 7.5 and 9.5 meters; and ≥ 9.5 meters.

Figure 9. Each case's width on the timeline. The cases in the upper row, i.e. the single-family cases, are categorized in the following categories: < 5.2 meters; between 5.2 and 5.8 meters; and ≥ 5.8 meters. However, the cases in the bottom row, i.e. the multiple-family cases are categorized in the following categories: < 6 meters; between 6 and 8 meters; and ≥ 8 meters.

3.3.2.2. Floor-to-ceiling height

Figure 10 shows how the sample is categorized in terms of floor-to-ceiling height. This

figure contains an additional row on top. The additional row shows the first floor's floor-to-ceiling height for all single-family houses. The first floor is the level directly above the main floor. The main floor is the level that includes the living room. The other two rows in Figure 10 show the main floor's floor-to-ceiling height for all houses.

It is often stated that the legally mandatory floor-to-ceiling height is, in general, representative for the actual floor-to-ceiling height, in a given time period (e.g. Liebrechts and van Nunen, 2014, p. 21). A greater floor-to-ceiling height results in substantially greater costs (see Gijssbers, 2011, pp. 33-34). So, why would anyone exceed the legally mandatory minimum? This phenomenon especially holds true for houses that have been built after the national building code's introduction in 1992. Since 1992, no house in the sample has exceeded the legally mandatory minimum floor-to-ceiling height by more than ten centimeters.

Before the national building code's introduction in 1992, regulations were neither completely uniform throughout the country nor completely uniform for every situation (see Scholten, 2001, pp. 11-29). Nonetheless, a clear trend can be seen in Figure 10. Between 1900 and 2003, the main floor's average floor-to-ceiling height has decreased steadily from about 3,0 meters to about 2,4 meters. Furthermore, the first floor's average floor-to-ceiling height has remained unchanged, i.e. 2,4 meters, throughout the period of 1915 to 2003.

Figure 10. The main floor's floor-to-ceiling height of each case on the timeline. Additionally, the extra upper row shows the first floor's floor-to-ceiling height for all single-family houses. All cases in all three rows are categorized in the following categories: < 2.6 meters; between 2.6 and 2.8 meters; and ≥ 2.8 meters.

3.3.2.3. Utilitarian rooms

A utilitarian room is a room that is intended for specific uses and not for a prolonged stay (Boekholt et al., 1974, p. 49). In the last 100 years, a new utilitarian room was introduced to the ordinary house, i.e. a bathroom. A bathroom is a separate room specifically intended for personal hygiene activities. Figure 11 shows that a bathroom was included in almost 97% of the post-Second World War houses, while a bathroom was only included in about 10% of the older houses. According to Prak (1991, p. 95), a bathroom had become a standard by 1914 in town houses in the Netherlands. Furthermore, in the municipality of Amsterdam, a bathroom became a mandatory feature for all houses in 1933. However, this law did not immediately lead to the desired results (Prak, 1991, pp. 174-175). The result shown in Figure 11 correspond rather well with the statements of Prak.

Figure 11. Whether or not a bathroom is present in each case on the timeline. Case #47, i.e. a multiple family case from 1950, is categorized as both a case with a bathroom and a case without a bathroom. This means that case #47 is a two-family house in which only one of the two units originally had a bathroom.

The bathroom's introduction is not the only change of the last 100 years to the house's utilitarian rooms. In the last 100 years, it became rare to build a house with underground storage. Figure 12 shows that almost 90% of the houses, before 1965, either had a basement or a basement closet. A basement closet is a small space, partially underground, which was primarily intended for the storage of food. In the sample, no single-family house after 1965 includes a basement or a basement closet. Thijssen (1999, p. 25) came to the same conclusion. In his study, there were also no single-family houses, after 1965, that included a basement or a basement closet.

Figure 12. Whether or not a basement or basement closet is present in each case on the timeline. Case #42, i.e. a multiple family case from 1925, and case #45, i.e. a multiple family case from 1934, are both categorized as a case with underground storage and as a case without underground storage. This means that both case #42 and case #45 are two-family houses in which only one of the two units originally had underground storage.

3.3.2.4. Spatial layout

Two features characterize a house's spatial layout: (1) private rooms; and (2) extra doors. Figure 13 shows the differences between three spatial layouts: (1) a basic layout; (2) a layout that includes an extra door; and (3) a layout that includes a private room. An extra door is a door that is not necessary to reach every room. The extra door is the one that is not part of the shortest route between a room and the main circulation space. The main circulation space in a house is generally the hallway. A room is termed private when it is not directly accessible from a house's main navigation space (see Alexander, 1977, pp. 610-613; Habraken, 1998, pp. 134-179). In other words, a private room is only accessible, from the hallway, by passing through another room.

Figure 13. The differences between three spatial layouts: (1) a basic layout; (2) a layout that includes an extra door; and (3) a layout that includes a private room. In this figure, a circle represents a room, and a line between two circles represents a door between those two rooms (see Hillier, 1993, pp. 11-14).

Figure 14 and Figure 15 show how the sample's main floors are categorized in terms of private rooms and extra doors, respectively. Four conclusions can be drawn from these figures. Conclusion #1: private rooms and extra doors are more common in multiple-family houses than in single-family houses. About 40% of the single-family houses, in the sample, has a basic layout, i.e. a layout without extra doors and without private rooms. However, less than 20% of the multiple-family houses, in the sample, has a basic layout. A multiple-family house usually only contains a single floor or level. A single-family house usually contains two or three floors. In multiple-family houses, more rooms need to be fitted in a single floor. As a result, the main floor's spatial layout is generally more straightforward in single-family houses than in multiple-family houses. Conclusion #2: between 1920 and 1945, a single-family house's main floor layout commonly included a private room, but no extra doors. In four of the six cases, the

Figure 14. Whether or not one or more private rooms are present in each case on the timeline. Four multiple family cases (case #39, case #40, case #42 and case #44) are categorized as both a case with one or more private rooms and a case without private rooms. This means that each of those cases is a two-family house in which only one of the two units originally had one or more private rooms.

Figure 15. Whether or not one or more extra doors are present in each case on the timeline. Case #38, i.e. a multiple family case from 1901, is categorized as both a case with one or more extra doors and a case without extra doors. This means that case #38 is a two-family house in which only one of the two units originally had one or more extra doors.

kitchen was only accessible, from the main circulation space, by passing through the living room. Conclusion #3: between 1945 and 1970, a single-family house's main floor layout commonly included an extra door, but no private rooms. About 65% of single-family houses, between 1945 and 1970, had an extra door in the main floor layout. This extra door connected the living room to another sitting room.

Conclusion #4: after 1970, a single-family house's main floor layout, commonly, neither include private rooms nor extra doors. Between 1970 and 2012, more than 75% of the single-family houses had a basic layout, i.e. a layout without extra doors and without private rooms. Figure 16 shows that, between 1970 and 2012, more than 90% of the houses had an open kitchen. Previously, it was common to have a separate room that people referred to as the kitchen. In 1970, it became common to have one large room that serves the purposes of both the kitchen and the living room. An open kitchen layout contains fewer rooms than a separate kitchen layout. Therefore, private rooms and extra doors became rare in a single-family house's main floor layout.

In the study of Thijssen (1999, p. 74), about 58% of single-family houses between 1968 and 1980 had an open kitchen. The oldest open kitchen layout in Thijssen's sample is from 1969. The result shown in Figure 16 correspond quite well with the statements of Thijssen. This study and Thijssen's study both identified the same turning point, i.e. the moment that the open kitchen became standard. However, Figure 16 shows a more immediate transition from a separate kitchen to an open kitchen, compared to Thijssen's results.

Figure 16. Each case's type of kitchen, i.e. separate kitchen or open kitchen, on the timeline.

Finally, a house's first-floor spatial layout did not change at all throughout the last 100 years. In the sample, 95% of the houses' first floors has a basic layout, i.e. a layout without extra doors and without private rooms (see Appendix 1).

3.3.3. Technical characteristics

3.3.3.1. Type of structure

The type of a house's structure is determined by three characteristics: (1) structural layout; (2) vertical elements; and (3) horizontal elements. Structural layout refers to the positioning of structural elements on the main floor. A single-span structure only includes structural elements at the boundaries of a housing unit's floorplan. However, a multiple-span structure and a mixed-span structure have structural elements in between those boundaries. Furthermore, in a multiple-span structure, vertical loads are transferred along a single axis, whereas in a mixed-span structure, vertical loads are transferred along at least two distinct axes. A structure's vertical elements are either walls, posts, or a mix of walls and posts. A structure's horizontal elements are either slabs, beams, or a mix of slabs and beams. Figure 17 shows how the types of structure are specified by

Figure 17. How the types of structure are specified by different combinations of the options under each of the three characteristics, i.e. (1) structural layout; (2) vertical elements; and (3) horizontal elements. Type A is a multiple-span structure of walls & beams. Type B is a multiple-span structure of walls & slabs. Type C is a single-span structure of walls & slabs.

different combinations of the options under each of the three characteristics.

Figure 18 shows how the sample is categorized in terms of type of structure, and Figure 19 shows the material from which each structure's horizontal elements were made. Three conclusions can be drawn from these figures. Conclusion #1: between 1900 and 1945, a house commonly was built with a multiple-span structure made from walls and wooden beams. More than 90% of the houses, before 1945, was built in this manner. Conclusion #2: between 1945 and 1975, a house commonly was built with a multiple-span structure made from walls and concrete slabs. Almost 70% of the houses, between 1945 and 1975, was built in this manner. In about 40% of these cases, the concrete slabs were made primarily by pouring concrete on site. In the other 60%, the concrete slabs were made by floor systems that involve prefab concrete elements.

Figure 18. Each case's type of structure on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: (A) multiple-span structure of walls & beams; (B) multiple-span structure of walls & slabs; and (C) single-span structure of walls & slabs.

Figure 19. The material, from which each structure's horizontal elements were made, on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: in-situ concrete; prefab concrete; and wood.

Conclusion #3: between 1975 and 2012, a house commonly was built with a single-span structure made from walls and concrete slabs. Between 1975 and 2012, 80% of the houses was built in this manner. In 30% of these cases, the concrete slabs were made primarily by pouring concrete on site. In the other 70%, the concrete slabs were made by floor systems that involve prefab concrete elements.

The result shown in Figure 19 deviate somewhat from Thijssen’s (1999) results. Figure 19 shows that only about 8% of the houses, between 1945 and 1980, was built with a first floor made from wooden beams. Furthermore, the most recent wooden floor, in the sample, is from 1956. In Thijssen’s study (1999), 19% of the houses, between 1945 and 1980, was built with a first floor made from wooden beams (p. 131), and the most recent wooden floor in his sample is from 1969 (p. 55). On the other hand, both this study and Thijssen’s study conclude that, by 1945, a wooden beam structure was no longer the most common type of structure.

3.3.3.2. Roof structure

Figure 20 and Figure 21 show how the sample is categorized in terms of roof type and roof structure’s material, respectively. About 70% of the houses, in the sample, was built with a wooden roof structure. More than 60% of the wooden roof structures, in the sample, is categorized as a side-gabled roof. Throughout the last 100 years, a single-family house commonly was built with a wooden side-gabled roof. Half of the single-family houses, in the sample, was built in this manner.

The oldest concrete roof structure, in the sample, is from 1959. Concrete is mostly used to build flat roofs. More than 80% of the concrete roof structures, in the sample, is categorized as a flat roof. Furthermore, these concrete flat roof structures are mostly used for multiple-family houses. More than 70% of concrete flat roof structures, in the sample, was used for blocks of flats (see Appendix 1). By 1955, it had become

Figure 20. Each case’s type of roof on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: side-gabled; flat; and mix or other.

Figure 21. The material, from which each roof structure is made, on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: concrete; wood; and steel.

common to build multiple-family houses with concrete flat roofs. Between 1955 and 2012, more than 60% of the multiple-family houses was built in this manner. However, before 1955, a multiple-family house commonly was built with a wooden side-gabled roof. Between 1900 and 1955, about 65% of the multiple-family houses was built in this manner.

3.3.3.3. Insulation

Figure 22, Figure 23 and Figure 24 show how the sample is categorized in terms of exterior wall insulation, roof insulation and ground floor insulation, respectively. Three conclusions can be drawn from these figures. Conclusion #1: between 1975 and 2012, the average exterior wall insulation has increased steadily from 0 millimeters to about 120 millimeters. Between 1900 and 1975, less than 5% of the houses was built with exterior wall insulation. However, between 1975 and 2012, 100% of the houses was built with exterior wall insulation.

Conclusion #2: between 1970 and 2012, the average roof insulation has increased steadily from 0 millimeters to about 110 millimeters. Between 1900 and 1970, 15% of the houses was built with roof insulation. However, between 1970 and 2012, almost 90% of the houses was built with roof insulation. Conclusion #3: between 1985 and 2012, the average ground floor insulation has increased steadily from 0 millimeters to about 150 millimeters. Between 1985 and 2012, about 95% of the houses was built with ground floor insulation. Furthermore, the oldest building that was built with ground floor insulation, in the sample, is from 1983.

In the study of Thijssen (1999, p. 93), no traditionally built houses before 1971 had exterior wall insulation. Furthermore, wooden sloped roofs in Thijssen's sample, from

after 1974, were all insulated (1999, p. 95). The result shown in Figure 22 and Figure 23 correspond quite well with the statements of Thijssen.

Figure 22. Each case's exterior wall insulation on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: 0 millimeters; between 10 and 100 millimeters; and ≥ 100 millimeters.

Figure 23. Each case's roof insulation on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: 0 millimeters; between 10 and 100 millimeters; and ≥ 100 millimeters.

Figure 24. Each case's ground floor insulation on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: 0 millimeters; between 10 and 100 millimeters; and ≥ 100 millimeters.

Finally, this chapter’s results do not confirm that it took 10 years for the use of the cavity wall to become a widespread practice (see Appendix 1), as was mentioned in the Method (see 3.2.4. Construction year).

3.3.3.4. Separating wall’s thickness

Figure 25 shows how the sample is categorized in terms of the total thickness of the separating walls, i.e. the walls that separates one house from another. Since 1980, the separating wall’s average thickness has increased. Between 1900 and 1980, the separating wall’s average thickness in the sample is a bit above 215 millimeters, while between 1980 and 2012, the separating wall’s average thickness in the sample is almost 250 millimeters.

The oldest building, in the sample, that was built with decoupled separating walls is from 1967 (see Appendix 1). A decoupled separating wall is a separating wall that contains two layers and a cavity in between those layers. After 1967, more than 40% of the single-family houses in the sample was built with decoupled separating walls. However, no multiple-family house, in the sample, was built with decoupled separating walls. These results deviate somewhat from Thijssen’s (1999) results. In Thijssen’s sample (1999, p. 41), the oldest building that was built with decoupled separating walls is from 1976.

Figure 25. The separating wall’s thickness of each case on the timeline. Both the single-family cases and the multiple-family cases are categorized in the following categories: < 225 millimeters; between 225 and 270 millimeters; and ≥ 270 millimeters.

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3.4. Discussion and conclusion

3.4.1. Discussion

To what extent does the house’s evolution justify demolition? The result section shows that many of the house’s characteristics have evolved throughout the last 100 years. However, not every evolution is equally harmful for a house’s longevity. How harmful an evolution is to a house’s longevity is determined by: (1) whether or not an evolution introduces a higher performance standard; and (2) whether an evolution reinvents or adds on the previously established ways of constructing buildings.

Figure 26 shows how well each of the identified evolutions matches with the description of: (1) reinvention or add-on; and (2) performance increase or performance decrease. Thus, for example, the more an evolution is positioned to the left, the more it is seen as a reinvention of the previously established ways of constructing buildings, instead of an addition onto it. Furthermore, the size of each circle shows how much that characteristic

Figure 26. How well each of the identified evolutions matches with the description of: (1) reinvention or add-on; and (2) performance increase or performance decrease. The size of each circle shows how much that characteristic has evolved in the last 100 years. Both the position and size of each circle are estimates of the author.

has evolved in the last 100 years.

According to Lichtenberg (2004, pp. 11-13), the construction industry mainly innovated in the 20th century by adding things onto the previously established ways of constructing buildings. He named this type of innovation “*innovation-by-addition*”. In Figure 26, these types of innovations are shown in quadrant #2 (the top right). With such innovations, the process of adding them on at a later stage is not that much different from including them in the initial design. Therefore, an innovation-by-addition – on its own – does not necessitate the replacement of houses.

However, a reinvention is the type of innovation that may – on its own – necessitate replacement, but only if it introduces a higher performance standard. For example, the switch from wood to concrete as one of the primary structural materials was the largest reinvention of the house in the 20th century (see Figure 26). However, this innovation’s aim was not to improve the standard of houses – previous houses were not suddenly inferior to the new ones. The switch from wood to concrete was beneficial to the maker, instead of the consumer.

In Figure 26, evolutions in quadrant #1 (the top left) are the best justification for the demolition and replacement of houses. However, not much has evolved in this quadrant. Not all of a house’s physical characteristics were included in this chapter. Therefore, it is possible that some relevant evolutions were overlooked, e.g. the evolution of a house’s aesthetical qualities. However, currently, the results indicate that the house’s evolution from 1900 to 2012, in terms of spatial and technical characteristics, provides little justification for its demolition. If this statement is true, i.e. if the house’s evolution provides little justification for its demolition, this implies one of two things: either (1) a building’s physical qualities are not significantly taken into account in the decision-making process of the building’s demolition; or (2), as stated by Thomsen and van der Flier (2011, p. 354), “...*housing [in contrast to non-residential functions] is a rather stable function with a long life cycle expectancy*”.

Statistics regarding the average lifespan of buildings are scarce, because most of today’s building stock is still relatively young (Thomsen, 2006, p. 7). The function of housing was examined in this chapter due to its importance in volume. However, non-residential buildings, on average, do not last as long as residential buildings (see Huuhka and Lahdensivu, 2016, p. 87, Table 10; O’Connor, 2004, pp. 6-7). Also, the vacancy rates for offices, for example, are generally much higher than the vacancy rates for residential buildings (e.g. see CBS, 2018). Therefore, it seems likely that, on average, the premature demolition of buildings primarily occurs in the non-residential building sector.

3.4.2. Conclusion

This chapter's aim was to determine how the ordinary house, in the Netherlands, has changed throughout the last 100 years. Firstly, in terms of a house's spatial characteristics, the following changes have occurred: (1) houses became deeper in 1990; (2) houses' main floor floor-to-ceiling height steadily became lower up to 2003, and houses' floor-to-ceiling height, i.e. the floor-to-ceiling height of both the main floor and the first floor, have become higher since 2003; (3) having a bathroom became a standard in housing in 1945; (4) having underground storage was no longer a standard in housing by 1965; and (5) having an open kitchen became a standard in housing in 1970.

Secondly, in terms of a house's technical characteristics, the following changes have occurred: (1) constructing floors with concrete slabs, instead of wooden beams, became a standard in housing in 1945; (2) single-span structures, instead of multiple-span structures, became a standard in housing in 1975; (3) insulated exterior walls, insulated roofs and insulated ground floors became a standard in housing in 1975, 1970 and 1985, respectively, and their insulation values have since gradually increased; and (4) separating walls became thicker in 1980.

However, none of these changes – on their own – seem to be sufficient reason for demolishing a house. It is likely that, on average, the premature demolition of buildings is primarily a problem of the non-residential building sector.

CHAPTER

4

How to set up criteria for
evaluating a building's
changeability?

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Chapter 4's purpose

The project goal is to create a method that can evaluate a building's changeability, and therewith support the design of changeable buildings. Chapter 4's purpose is to develop both a review-based understanding of, and comprehensive support for, changeability in building design. However, changeable buildings is not the societal end goal, it is the means through which the end goal is pursued. This dissertation's societal end goal is to contribute towards mitigating the problem of resource depletion. The need for a method that can evaluate a building's changeability is based on the following premise: (1) a method for evaluating a building's changeability will improve the changeability of future buildings; (2) buildings with greater changeability will have greater longevity; and (3) when buildings have greater longevity, the problem of resource depletion is significantly reduced. Chapter 4's outcome must explain what makes a building changeable, and how this works.

4.1. Introduction

4.1.1. Background

In Zurich (Switzerland), buildings do not even last half as long as they used to (Aksözen et al., 2017, p. 254, Fig. 10). Furthermore, a study (O'Connor, 2004) in Minneapolis–Saint Paul (USA) shows that especially non-residential buildings generally do not last as long as architects, engineers and developers expect them to last. In Finland, for example, non-residential buildings are on average only 43 years old when they are demolished (Huuhka and Lahdensivu, 2016, p. 87, Table 10). The premature demolition of buildings is a major waste of resources, and improving buildings' longevity will help solve the problem of depleting resources (see de Laat, 2019).

In design, it is good practice to first try to blame the product for a fault, instead of the users (see Norman, 2013, pp. 162-216). However, it is already a challenge to create a building or product that meets people's current needs, let alone people's future needs. A designer must first learn how to evaluate how well a building performs in terms of expected longevity, before he or she can learn to create long-lasting buildings (see Krathwohl, 2002). A building's expected longevity is determined by both its maintainability, i.e. the ability to allow for wear and tear, and its changeability, i.e. the ability to comply with future change. This chapter's focus is on evaluating a building's changeability.

A changeable building is a building that is optimized from the perspective of future change. However, future change is neither a single nor a specific event; future change represents countless possible events. In other words, the optimization goal is non-specific. This makes it difficult to evaluate a building's changeability. Evaluation methods are mostly useful when they are generally applicable. This means that the subject of an evaluation, in an evaluation method, must be non-specific. Methods of evaluating a building's changeability already exist (see Heidrich et al., 2017, pp. 289-290; Schmidt III, 2014, pp. 97-99). However, in most of these methods, the problem of an uncertain future is simplified to a problem that has a few universal solutions. In other words, these methods prescribe specific solutions to optimize a non-specific object for a non-specific goal. When the optimization goal is unclear, solutions - and the methods that prescribe them - cannot be validated.

4.1.2. Proposal

4.1.2.1. Introduction

In this chapter, a method of evaluating a building's changeability is proposed in which

optimization goals are specified during the evaluation process. Since the optimization goals are specified in the method, the solutions that the method prescribes can be validated. This method has a scenario-based approach. In most forecasting methods, the logic of scenario development is the primary focus; “*very little is said about the actual creation of the stories [scenarios] in most methods*” (Bishop et al., 2007, p. 6). For this chapter, the opposite is true: the primary focus is the development of support for the actual creation of both scenarios and the optimizations associated with each of these scenarios. But first, the general method, and the role of scenarios in it, is briefly introduced. Figure 27 shows the proposed method of evaluating a building’s changeability.

4.1.2.2. Scenarios

As shown in Figure 27, step 1 is developing scenarios. A scenario is a description of a mismatch that can arise when a building is confronted with a certain change. For example, when a couple that is living in an apartment decides to have children, their apartment can quickly become too small. Scenarios are developed to identify potential problems, and potential problems are identified to determine which design solutions are useful.

Figure 27 also shows that changeability levels are used to support step 1. A categorization into levels contains both: (1) a breakdown of the subject into parts; and (2) a manner of arranging these parts. Therefore, the changeability levels show both the parts of the subject that need to be taken into account and the sequence in which these parts should be taken into account. As will be discussed further in “4.3.1. *Changeability levels*”, this will be very helpful when developing scenarios.

4.1.2.3. Design solutions

As shown in Figure 27, step 2 is developing design solutions. These design solutions are solutions to potential problems, i.e. problems that have not arisen yet. Unlike existing problems, potential problems are solved by making sure that, when they arise, they are not such a big deal. In this study, a problem refers to a mismatch between what people demand and what the building provides. Furthermore, a design solution refers to a set of designable conditions that make a certain manner of addressing a certain mismatch significantly easier. For example, outdated installations are replaced more easily when they are entirely accessible.

In addition, the following is shown in Figure 27: (1) changeability levels are used to limit the possible outcomes of step 2; and (2) types of design tactics are used to support

step 2. Concerning the use of changeability levels, each design solution specifies a manner of addressing the mismatch when it arises. However, the effort that is still needed to address the problem, when it arises, must be proportional to the size of the problem – otherwise who would address it? In step 2, the changeability levels help make sure that no such unfeasible design solutions are developed.

Concerning the use of types of design tactics, a design solution refers to a set of designable conditions, while a design tactic refers to an individual designable condition. To develop a design solution one must first identify the individual designable conditions that are beneficial when addressing a certain mismatch in a certain manner, and then combine them into a complete solution. As will be discussed further in “4.3.2. *Types of design tactics*”, the types of design tactics will be very helpful when identifying individual conditions.

4.1.2.4. Likelihood & severity

As shown in Figure 27, step 3 is assessing the likelihood and severity of scenarios. Not every scenario is equally important. Scenarios that are likely to arise should be prioritized over scenarios that are not likely to arise. Furthermore, scenarios with severe consequences should be prioritized over scenarios with minor consequences. In the field of risk management, risk managers generally use risk matrices to prioritize which risk needs to be addressed first (see Duijm, 2015). In step 3 a similar procedure is followed: a weighting factor is determined for each scenario based on likelihood x severity.

4.1.2.5. Weighted evaluation criteria

As shown in Figure 27, in step 5, weighted criteria are used to evaluate a building. The criteria are based on the design solutions that have been developed. Thus, to what degree have these design solutions been implemented in the building? Furthermore, the weighting is based on the importance of each scenario (likelihood x severity). Thus, how useful is it that a design solution has been implemented, or how severe is it that a design solution has not been implemented?

Figure 27. The proposed method of evaluating a building's changeability. This figure was made according to the principles of Structured Analysis (Ross, 1977). Thus, each box represents an activity in which input is transformed into output. Furthermore, arrows connected to the left, right, bottom and top side of a box represent input, output, support and control, respectively.

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4.2. Method

4.2.1. Introduction

This chapter's aim is to determine: how to set up criteria for evaluating a building's changeability? In other words, how to do step 1 and 2 of the proposed method (see Figure 27). The basics of these steps have already been discussed (see 4.1.2. Proposal). However, for these steps to work, some inputs still need to be developed, i.e. changeability levels and types of design tactics. Therefore, the rest of this chapter will mainly focus on both the development of these inputs and their use within the method.

4.2.2. Changeability levels

A top-down approach is used to define changeability levels. This means that the approach's starting point is a theoretical concept, i.e. a building's changeability. This concept is then broken down into parts. To do such a breakdown, there are only two rules that must be followed: (1) the parts are mutually exclusive, i.e. non-overlapping (Leupen and Mooij, 2011, p. 38); and (2) every single aspect of the concept must go into the parts (Ross, 1977, p. 18). Afterwards, the changeability levels are defined by these parts.

4.2.3. Types of design tactics

A bottom-up approach is used to define types of design tactics. This means that numerous design tactics are the approach's starting point. These design tactics are then grouped into types. This set of types must then represent all conceivable design tactics. However, first, numerous design tactics must be collected and, before that, sources must be identified from which they can be extracted. Figure 28 describes the various searches that have been conducted to find relevant literature. As a result of these searches, 92 relevant journal papers were identified. In addition, the book "*How buildings learn*" (Brand, 1994) was added to this list of sources – it seemed to be an essential source. In the end, there was no mention of a design tactic in 20 of the 93 sources. Throughout the other 73 sources, a total of 549 instances have been identified in which a design tactic was mentioned. Table 10 shows the number of instances that have been identified per source. All 549 mentions of a design tactic are included in Appendix 2.

Finally, the "*constant comparative method*" (Glaser and Strauss, 1967, pp. 105-113) is used to define types of design tactics. This method prescribes the following procedure: (1) design tactics must be put into categories; (2) categories must constantly be compared to avoid any overlap between categories; and (3) the number of categories

must be reduced to an appropriate number.

relevant hits / hits	description of search activity				publication range	discipline excluded	keyword excluded
8 / 36 7 / 20 3 / 47 16 / 62 11 / 80 25 / 200	<i>all text</i>		<i>all text</i>		Jan. 2000 ↓ Apr. 2016	non-relevant ones	none
	("design for change") or		(product) or (building)				
	("design for adaptability") or		or				
	("adaptable architecture") or		("build environment")				
	("adaptable building") or						
	("building flexibility") or						
("adaptive reuse")							
5 / 42	<i>all text</i>				Jan. 2000	non-relevant ones	none
	("transformable structure") or ("transformable building") or ("building transformation")				↓ Apr. 2016		
26 / 386	<i>keywords</i>		<i>all text</i>		Jan. 2000	non-relevant ones	non-relevant ones
	(flexib*) or (adapt*)		(product) or (building) or ("build environment")		↓ Apr. 2016		
24 / 306	<i>abstract</i>	<i>abstract</i>	<i>abstract</i>	<i>abstract</i>	May 2011 ↓ Apr. 2016	none	none
	(building) or ("build environment")	(chang*)	(architecture) or (design)	(flexibility) or (flexible) or (adaptability) or (adaptable) or (transformable) or (transformation)			

Figure 28. The various searches that have been conducted to find relevant literature. The following is described, per search activity: (1) the components (e.g. specific phrases or variations on words) a search activity comprises, and whether these components apply to keywords, abstracts or all of the texts; (2) the regarded publication range; (3) whether or not specific keywords or disciplines were excluded from a search; and (4) the number of total and relevant hits encountered.

sources	# of mentions	sources	# of mentions
Altan et al., 2015	7	Langston et al., 2008	2
Arge, 2005	13	Lin, 2011	4
Beisi and Yingying, 2011	12	Mantab-uz-Zaman, 2011	4
Belausteguigoitia et al., 2011	11	March et al., 2012	14
Brand, 1994	77	Meins et al., 2010	2
Bruce et al., 2015	8	Nijs et al., 2011	4
Bullen and Love, 2011a	16	Paslawski and Rozdzyńska, 2013	2
Bullen and Love, 2011b	1	Pinder et al., 2013	14
Bullen and Love, 2011c	3	Remøy and van der Voordt, 2014a	11
Conejos et al., 2016	2	Remøy and van der Voordt, 2014b	2
de Neufville, 2008	3	Remøy et al., 2011	7
Dhar et al., 2013	12	Ren et al., 2014	6
Dovey and Fisher, 2014	6	Ross et al., 2016	14
Eguchi et al., 2011	20	Saari et al., 2007	3
Engel and Browning, 2008	6	Saghafi and Ahmadi, 2011	1
Engel and Reich, 2015	7	Saigo et al., 2011	9
Fawcett et al., 2012	2	Schmidt III and Eguchi, 2014	9
Fernandez, 2003	5	Schmidt III et al., 2014	7
Fletcher et al., 2009	9	Schwehr, 2011	5
Georgiadou et al., 2012	3	Slaughter, 2001	11
Gijsbers and Lichtenberg, 2014	8	Steadman, 2006	2
Gosling et al., 2013	9	Sung-Hwa and Beisi, 2012	7
Greden and Glicksman, 2005	3	Vandenbroucke et al., 2015	3
Grover and Grover, 2015	8	Vimpari and Junnila, 2016	3
Halvitigala and Reed, 2015	22	Walker, 2010	4
Hamraz et al., 2013	1	Walker et al., 2013	2
Hassanain, 2006	18	Wiendahl et al., 2007	10
Hein and Houck, 2008	1	Wilkinson et al., 2009	1
Hertzberger, 2014	8	Wilkinson, 2012a	5
Hunter, 2006	10	Wilkinson, 2012b	7
Isaac et al., 2014	7	Wilkinson, 2014a	12
Israelsson and Hansson, 2009	3	Wilkinson, 2014b	4
Itard and Klunder, 2007	5	Wilkinson and Reed, 2011	8
Khan and Dhar, 2012	11	Wong, 2010	8
Langston and Shen, 2007	1	Worthington, 2001	4

Table 10. The number of mentions of a design tactic that have been identified per source.

4.3. Results

4.3.1. Changeability levels

4.3.1.1. Introduction

In the Introduction (see 4.1.), changeability is defined as the ability to comply with future change. A change is the cause of a mismatch. Thus, the level of change says something about the scale of this cause. Furthermore, a building is referred to as ‘able’ when its design includes design solutions to address mismatches in feasible manners. However, such a manner is only thought to be feasible when the level of adjustments it involves is, at least, proportional to the severity of the mismatch’s consequences. Therefore, when defining changeability levels, both aspects are important: (1) the level of change a building can comply with; and (2) the level of adjustments a building can allow for.

Schmidt III et al. (2010) defined six adaptability types: (1) adjustability; (2) versatility; (3) refitability; (4) convertibility; (5) scalability; and (6) movability. These adaptability types range from types related to small adaptations, that are frequently needed, to types related to major adaptations, that are hardly ever needed (Schmidt III, 2014, p. 174). Schmidt’s adaptability types partially fulfil this chapter’s aim. However, these adaptability types are arranged in terms of type of change, and not necessarily in terms of the scale of change. Therefore, some revisions are necessary. The result of these revisions is shown in Figure 29.

As shown in Figure 29, a building’s most basic ability to comply with changes, i.e. changeability level 1, is adjustability. A building’s adjustability is determined by how capable it is in complying with small-scale changes, by allowing for small-scale adjustments. Changeability level 2 is versatility. A building’s versatility is determined by how capable it is in complying with medium-scale changes, by allowing for small-scale and medium-scale adjustments. Changeability level 3 is convertibility. A building’s convertibility is determined by how capable it is in complying with large-scale changes, by allowing for small-scale, medium-scale and large-scale adjustments. Finally, a building’s most advanced ability to comply with changes, i.e. changeability level 4, is reconfigurability. A building’s reconfigurability is determined by how capable it is in complying with extra-large-scale changes, by allowing for small-scale, medium-scale, large-scale and extra-large-scale adjustments.

The following section will explain the differences between both the different scales of change and the different scales of adjustments.

Figure 29. The subject area that each changeability level covers, in terms of both: (1) the scale of changes a building can comply with; and (2) the scale of adjustments a building can allow for.

4.3.1.2. The level of change

As previously mentioned, a change is the cause of a mismatch. In this study, a change refers to a change at the user's side, i.e. a change in the user's characteristics or activities. The level of change is mainly determined by the number of persons involved. A distinction is made between four size classes: (1) individual; (2) group; (3) organization; and (4) community.

The group size class refers to 7 to 20 occupants. A set of 7 or more persons are primarily perceived as a group of people, instead of a number of distinct individuals (see Alexander et al., 1977, p. 505). The organization size class refers to 20 or more occupants. For such a group, it is no longer possible for each member to interact individually with every other member (Caplow, 1957, pp. 486-487), and therefore an organizational structure is required. The community size class refers to all occupants and numerous non-occupants. This is the only category that has little to do with the use of the building, instead it is concerned with how the building fits in with its surroundings.

A change on the individual, group, organization and community level is categorized as a small-scale, medium-scale, large-scale and extra-large-scale change, respectively.

4.3.1.3. The level of adjustments

As previously mentioned, a building is referred to as 'able' when its design includes design solutions to address mismatches in feasible manners. However, such a manner is only thought to be feasible when the level of adjustments it involves is, at least, proportional to the severity of the mismatch's consequences. The level of adjustments

is determined by both: (1) the type of elements involved; and (2) the type of intervention involved. The type of elements are categorized according to Brand's (1994, p. 13) well-known building layers: (1) stuff; (2) space plan; (3) services; (4) skin; and (5) structure. Brand's sixth layer, i.e. site, has been left out.

Concerning the type of intervention, a distinction is made between five types: (1) reinterpret, i.e. change how something is used; (2) adjust, i.e. switch between pre-established settings; (3) modify, i.e. alter the finishing layer; (4) alter, i.e. add and remove elements; and (5) reconfigure, i.e. change the composition of elements. In this study, adjustments are categorized as either small-scale, medium-scale, large-scale or extra-large-scale adjustments. In Table 11, each combination of a type of elements and a type of intervention has been put into one of these four categories.

	stuff	space plan	services	skin	structure
reinterpret	small	small	small	small	small
adjust	small	medium	small	small	large
modify	medium	medium	medium	medium	medium
alter	medium	large	large	large	extra large
reconfigure	medium	large	large	extra large	extra large

Table 11. How the type of elements involved and the type of intervention involved determines whether an adjustment is categorized as a small-scale, medium-scale, large-scale or extra-large-scale adjustment.

4.3.1.4. How to do step 1: developing scenarios

Now that the changeability levels have been defined, how are they used to support step 1, i.e. developing scenario? As previously mentioned (see 4.1.2.2. Scenarios), a scenario is a description of a mismatch that can arise when a building is confronted with a certain change. Thus, a scenario describes a causal relation, i.e. an if-this-than-that relation, that contains two primary components: (1) the change; and (2) the mismatch. The changeability levels mainly support the development of the first component, i.e. the change.

Based on the different levels of change, 13 changes can be developed. These changes are listed in Table 12. Not all of these 13 changes are equally realistic, however that is something that will be sorted out in the method's step 3. Firstly, a change on the individual level can either be a change in the user's characteristics or a change in the user's activities. Secondly, starting from the group level, the user refers to multiple

level	type of change	sub-type	specific change	mismatch
1	user's characteristics	average individual	person A > person B	local insufficiency
1	user's activities	-	personal task A > personal task B	local insufficiency
2	user's characteristics	average individual	group A > group A/B	local insufficiency
2	user's characteristics	total # of individuals	group A > group A+	local insufficiency
2	user's activities	-	group task A > group task B	local insufficiency
3	user's characteristics	average individual	organization A > organization A/B	total insufficiency
3	user's characteristics	total # of individuals	organization A > organization A+	total insufficiency
3	user's characteristics	relations	organization A > organization A.2	total insufficiency
3	user's activities	-	organization A > organization B	total insuf./excess.
4	user's characteristics	average individual	community A > community A/B	total insufficiency
4	user's characteristics	total # of individuals	community A > community A+ or A-	local/total insufficiency
4	user's characteristics	relations	community A > community A.2	local/total insufficiency
4	user's activities	-	district task A > district task B	total insufficiency

Table 12. A list of 13 changes that have been developed based on the different levels of change. The levels 1, 2, 3 and 4 represent a small-scale, medium-scale, large-scale and extra-large-scale change, respectively.

individuals. Therefore, the user's characteristics can change both in average and in total. Thirdly, starting from the organization level, individuals interact according to formalized relations. Therefore, the user's characteristics can change both in terms of individuals and in terms of relations.

All these individual changes can result in mismatches. A mismatch generally means that a building no longer fulfils people's requirements – something is lacking. For example, there can be insufficient operating space, ventilation capacity or privacy. Such problems can occur locally or throughout the entire building. Furthermore, there is also one situation in which too much of something is a bad thing, i.e. when the building is being sold. When there is a significant excess of something, e.g. cooling capacity, a potential buyer will feel like they are asked to pay extra for something that they do not need.

Thus, to develop a scenario, a person has to select one of the changes in Table 12 and then ask him- or herself: what could go wrong?

4.3.2. Types of design tactics

4.3.2.1. Introduction

As previously mentioned (see 4.1.2.2. Scenarios), scenarios are developed to identify potential problems, and potential problems are identified to determine which design solutions are useful. Thus, after the scenarios have been developed, the next step is to link each scenario to at least one design solution. A design solution refers to a set of designable conditions that make a certain manner of addressing a certain mismatch significantly easier. To develop a design solution one must first identify the individual designable conditions that are beneficial when addressing a certain mismatch in a certain manner, i.e. the design tactics, and then one must combine them into a complete solution.

There are three manners to address a mismatch: (1) reinterpret the use of a part of the building to make the use more suitable for the new setting; (2) alter a part of the building to make the part more suitable for the new setting; and (3) accept that not every part of the building will be precisely as it should be in the new setting. For each of these actions, i.e. reinterpret, alter and accept, there are certain conditions that will help their execution. These beneficial conditions are described in the design tactics. A design solution is often composed of several design tactics, and it will also often involve multiple different actions.

The development of a design tactic is no different from the process of coming up with an idea: people go through their memories and they select something that is

appropriate. Therefore, it is important that people have adequate knowledge about the specific subject matter, because nothing can be found what is not already there (Jungermann and Thüring, 1987, p. 250). Furthermore, not all information that is stored in a person's memory is always fully accessible. Information is retrieved more easily, from a person's memory, when he or she is reminded of the heading under which it is mentally filed (Tulving and Pearlstone, 1966). A categorization into types supports the development of design tactics by making it easier to retrieve relevant information. Furthermore, the specific examples on which each type is based can help a person gain adequate knowledge about the subject matter.

In this chapter, the 549 mentions of a design tactic, that are included in Appendix 2, have been grouped into 10 types of design tactics. Table 13 shows: (1) the 10 types of design tactics; (2) the action, i.e. reinterpret, alter or accept, that each type is meant to support; and (3) the number of mentions that each type is based on. In the following section, each of these types will be described individually. Furthermore, in each description, two or three examples are provided of the design tactics on which the type is based. All mentions on which each type is based are included in Appendix 2.

type	action	# of mentions
overdesigned	reinterpret	91
blank	reinterpret	76
uniform	reinterpret	82
diverse	reinterpret	23
appropriate	reinterpret	69
undemanding	alter	82
convenient	alter	58
robust	alter	14
unique	accept	14
intelligible	reinterpret / alter	29

Table 13. A list of the types of design tactics. The table also shows: the action, i.e. reinterpret, alter or accept, that each type is meant to support; and the number of mentions that each type is based on.

4.3.2.2. Benefit of overdesigned things

To reinterpret the use of a part of the building, it is beneficial to have overdesigned parts and properties. Overdesigned things, i.e. things that have been designed to

a higher standard than usual, are less likely to be insufficient for more demanding plans. Therefore, overdesigned things are more likely to be useful in a new setting. For example, Slaughter (2001, p. 213) argued how “...*structural members with higher capacity than currently required for the immediate design loads can provide the opportunity to add to the building in the future*”. Otherwise, the loadbearing structure would need strengthening before, for instance, an extra storey can be added.

Furthermore, Halvitigala and Reed (2015, p. 488) argued that acoustical ceilings that absorb noise and minimize the sound propagation adequately are necessary in an open plan office environment. Therefore, the conversion to an open plan is made easier by already having such ceilings. Finally, according to Brand (1994, p. 170) and Eguchi et al. (2011, p. 82), many of the 1960s and 1970s office buildings lack the floor-to-floor height that is needed to add a raised floor or a suspended ceiling. As a result, the latest service devices cannot be added to those buildings in the conventional manner. This problem would not have occurred if those buildings were built with a greater floor-to-floor height.

4.3.2.3. Benefit of blank things

To reinterpret the use of a part of the building, it is beneficial to have blank parts and properties. Blank things, i.e. things that have been left empty, are less likely to contain features that are misplaced in another setting. Therefore, blank things are more likely to be useful in a new setting. For example, columns and walls are referred to as “*restricting*” (Bruce et al., 2015, p. 160), a large number of them can make a building “*inappropriate for any change of use*” (Bullen and Love, 2011c, p. 39) and by keeping large portions of the building free of such things allows for more easy reconfiguration to suit changing requirements (Ross et al., 2016, p. 423).

Furthermore, similarly to how columns and walls can be seen as obstacles in an empty floorplan, windows can be seen as obstacles in a blank wall: Wong (2010, pp. 181-182) argued how the presence of windows “*severely*” limits the options of placing walls attached to the outer wall. Finally, Dhar et al. (2013, p. 150, Table I) argued that exposed roof beams constrain where one would add partitions – the clear presence of a grid directs the placement of things and therewith confines one’s freedom in positioning. However, when a ceiling is completely blank, no situation would occur in which one feels awkward for, for instance, placing an interior wall just next to a structural beam.

4.3.2.4. Benefit of uniform things

To reinterpret the use of a part of the building, it is beneficial to have uniform parts

and properties. Uniform things, i.e. things that share certain properties throughout the building or system, are likely to be as suitable, for another purpose, as for the original purpose. Therefore, uniform things are more likely to be useful in a new setting. For example, Beisi and Yingying (2011, p. 24, 25) argued that in traditional Chinese architecture, differences in the function of rooms were only evident by the furniture placed within them – rooms shared similar spatial dimensions. As a result, only the furniture needs to be moved to, for instance, change a dining room into a bedroom. Furthermore, Wilkinson (2014a, p. 254) argued that a central location for the services core provides “*greater scope for sub-dividing the floor plate*”. Positioning the entrance to a floor, for both people and pipes, in the centre of a building has the following consequences: (1) the surrounding space naturally breaks down into evenly sized parts; and (2) these parts are positioned equally, in distance, from this services core. Therefore, no single part is more suitable for a particular purpose than another. Finally, Schmidt and Eguchi (2014, p. 79) argued how counters, tables and shelves can be used as handrails by positioning them on a height which is appropriate for both functions.

4.3.2.5. Benefit of diverse things

To reinterpret the use of a part of the building, it is beneficial to have diverse parts and properties. Diverse things, i.e. things that have certain properties that are unique within the building or system, are less likely to be part of a whole that is – in its entirety – unsuitable for another purpose. Thus, a group of diverse things is more likely to include things that are useful in a new setting. For example, de Neufville (2008, p. 57) argued that to minimize, possibly premature, irrevocable commitments, one can “...*simultaneously create both traditional and low-cost facilities at a new airport, to appeal to the range of possible customers*”. When either the traditional or the low-cost facilities become more popular, one can always emphasize and expand on those sections of the complex.

Furthermore, Khan and Dhar (2012, p. 58) argued, concerning housing, that “*when a choice over moving or improving has to be made, and if the users are tenants, it is probably easier to decide to move*”. In other words, when a building contains diversely-sized apartments, people do not need to alter their apartments to live bigger or smaller – they can also move to a different apartment within the building.

4.3.2.6. Benefit of appropriate things

To reinterpret the use of a part of the building, it is beneficial to have appropriate parts and properties. Appropriate things, i.e. things that have certain properties that

are common outside the building or system, are less likely to be unsuitable within another setting. Therefore, appropriate things are more likely to be useful in a new setting. For example, Grover and Grover (2015, p. 309) argued that “...a cinema may become a bingo club and then a church”, since all these function share certain essential characteristics, namely: (1) they need “...to accommodate large numbers of people taking part in a sedentary leisure activity”; and (2) provide “...the ability for large numbers of people to enter or leave the building at the same time”.

Furthermore, Eguchi et al. (2011, p. 77) argued how a smaller grid size, one typically used for shopping centres and parking as opposed to offices, can add to the convertibility of an office building. A building with larger spans is considered to be inappropriately costly for this particular conversion, since (1) larger spans are associated with higher costs and (2) it is common for shopping centres and parking to have smaller spans. Finally, Lin (2011, p. 21) argued that “*Metabolist*” buildings often have a below average floor/area ratio, and that, therefore, a lot of these buildings have been replaced by more “*economically viable*” buildings.

4.3.2.7. Benefit of undemanding things

To alter a part of the building, it is beneficial to have undemanding parts and properties. Undemanding things, i.e. things that require few activities to be assembled, disassembled and operated, are more likely to be altered, when needed. Therefore, undemanding things are less of an obstacle for new settings. For example, Sung-Hwa and Beisi (2012, p. 21) described how, initially, four separate hanging panels were used as a partition between two rooms in a particular traditional Korean building. These panels were hinged on the structure directly above them. To open up the entire wall, one had to lift up each of the four panels separately and one had to attach each of them to hooks that were hanging from the ceiling. Eventually, three of the four separate panels were replaced by a single much larger panel. As a result, the task of opening up the entire wall was reduced from four to two activities of lifting panels and hooking them up on the ceiling.

Furthermore, Dhar et al. (2013, pp. 150-152) argued that one should avoid installing major wiring work in “*relatively non-permanent*” walls. Otherwise, a re-installation of wiring systems is required with every removal or replacement of such walls. This would make it a lot harder to make any major alterations to the partition walls.

4.3.2.8. Benefit of convenient things

To alter a part of the building, it is beneficial to have convenient parts and properties.

Convenient things, i.e. things that require no cumbersome activities to be assembled, disassembled and operated, are more likely to be altered, when needed. Therefore, convenient things are less of an obstacle for new settings. For example, Schmidt et al. (2014) argued “*the need to reduce chunks sizes*” to end up with dimensions which are “*manageable*” (p. 162) – especially volumetric solutions provided difficulties (p. 180) when alterations were required. A flat board, for instance, is easier to get a grip on and easier to manoeuvre through an opening than a bulky three-dimensional object. Furthermore, Wilkinson and Reed (2011, p. 732) argued how “*internal adaptations are easier to carry out*” when one can gain entry without having to disrupt the possible use of adjoining spaces. For instance, it is easier to move materials to a room when it is directly accessible from the outside – transporting stuff through a lot of doors and over stairs is not ideal. Furthermore, transporting materials through spaces that are still in use is no better.

4.3.2.9. Benefit of robust things

To alter a part of the building, it is beneficial to have robust parts and properties. Robust things, i.e. things that are tolerant to physical stress, are more likely to be altered, when needed, because they are less likely to break during alterations. Therefore, robust things are less of an obstacle for new settings. For example, Bruce et al. (2015, p. 160) argued that “*...the quality of the building’s internal structure and the durability of the materials that it was initially constructed from are very important*”. When a building is not sturdy enough to endure the additional stress of reconstruction activities, a lot of parts will need replacements.

Furthermore, Saigo et al. (2011, p. 10) argued that buildings in Japan from the late 8th to the late 12th century did not last as long as the buildings from both the preceding and succeeding period. According to Saigo et al., this was caused by the use of structural elements that were not as robust by comparison. Such comparatively fragile structures are less durable in general, but they are also more difficult to adapt.

4.3.2.10. Benefit of unique things

To accept that a part of the building is not exactly as it is supposed to be, it is beneficial to have unique parts and properties. Unique things, i.e. things that have certain properties that are uncommon outside the building or system, are more likely to be cherished – because they are difficult to replace. Therefore, unique things are more likely to be forgiven for their flaws. For example, Brand (1994, p. 109) argued that “*strangeness*” is a “*trait that invites longevity*”. He illustrated this statement with the example of

an “*adorably tiny stone hut*” built, in the 16th century, spanning a small brook. This building contains just two rooms, one for each story. Normally, not a lot of uses suit a building of this size. Nonetheless, its uses over the centuries have been numerous and quite diverse.

Furthermore, Eguchi et al. (2011, pp. 80-81) argued, concerning the conversion of an old office building into residential units, that one can drive market value by emphasizing the uniqueness offered by the original characteristics. In other words, that a residential building used to be an office is what sets it apart from all other residential buildings. Furthermore, these unique properties make it a more valuable building.

4.3.2.11. Benefit of intelligible things

It is beneficial to have intelligible parts and properties, both (1) to reinterpret the use of a part of the building and (2) to alter a part of the building. Intelligible things, i.e. things that are easily understandable through common sense, are less likely to be written off by people that do not completely understand their potential. Therefore, intelligible things are more likely to be reinterpreted and altered, when needed. For example, Slaughter (2001, p. 215) argued how “*...the predictability of the layout of a system and its components, particularly for those elements that are... hidden... can provide critical signals to reduce the duration and extent of demolition to find the required components*”. For instance, a change needs to be made to the cables that run through the walls and structure of a building. To do so, it would be easier if all cables had been placed at consistent and recognizable locations (e.g. right next to the columns), instead of behind the walls without a clear logic.

Furthermore, Brand (1994, p. 135) argued that “*...huge free-span interior spaces [are] actually a loss for intuitive adaptability*”. He stated that “*...columns articulate space in a way that makes people feel comfortable making and remaking walls...*” (p. 135). In other words, the possibilities of a floor plan that includes multiple columns are more easily understood, compared to a floor plan that is free of columns, and therefore it is easier to make the best use of a floor plan with columns.

4.3.2.12. How to do step 2: developing design solutions

Step 2 is developing design solutions. As previously mentioned (see 4.1.2.3. Design solutions): (1) changeability levels are used to limit the possible outcomes of step 2; and (2) types of design tactics are used to support step 2. Now that both the changeability levels and the types of design tactics have been defined, how are they used?

Firstly, a design solution is always developed for a specific scenario. This means that,

at the start of step 2, the change is known. The change's level determines the maximum level of adjustments that may be involved in a design solution to the problem (see Figure 29) – more effort would not be justified by a problem of that size. Furthermore, once the scenario is known, the mismatch is also known. The mismatch suggests what needs to be adjusted. For example, when there is insufficient cooling capacity, the building's services need an adjustment, or when there is insufficient operating space, the building's space plan needs an adjustment. Based on the maximum level of adjustments that is permitted, one can look up the specific interventions that may be involved in a design solution to the problem in Table 11.

Secondly, once the limitations of a design solution are known, the development can start. A design solution is generally centred around a specific intervention, e.g. a reinterpretation or an alteration. The development of design solutions starts by checking the design tactics that are directly associated with this type of intervention (see Table 13). Afterwards, one must ask him- or herself: which other design tactics can be beneficial to any aspects of the solution?

Two examples will be given. Both are examples of a design solution to the following potential problem: the building's cooling capacity is insufficient. Example 1 is a design solution centred around a reinterpretation of the cooling service. This design solution is rather straightforward: design the building's cooling capacity for the worst-case scenario. It is entirely based on a single type of design tactic: oversized building parts and properties.

Example 2 is a design solution centred around an alteration of the cooling service. This design solution is more complicated: (1) situate the installation space in a, for the worker, ergonomically accessible location; (2) cover the installation space by as few parts as possible; (3) use covering parts that are small and light enough for a single person to lift them; (4) use covering parts that are strong enough to withstand disassembly and reassembly; (5) do not use chemical connections to interconnect the covering parts; (6) use covering parts that are identical to one another; (7) oversize the height of the installation space; and (8) position the parts of the installation systematically. This design solution is based on six types of design tactics: oversized, convenient, undemanding, robust, uniform and intelligible building parts and properties.

4.4. Discussion and conclusion

4.4.1. Discussion

A scenario-based method of evaluating a building's changeability is proposed in this chapter. In this method, a building is judged by the presence or absence of certain key performance indicators. This is no different from most other methods of evaluating a building's changeability (e.g. Wilkinson, 2014b). However, what is different about this method is that the key performance indicators are not determined before the evaluation, but during the evaluation process: first the optimization goals are specified, and then the key performance indicators are determined.

The difficult part of the key indicator model is not identifying indicators, it is determining valid weighting factors for each of those indicators (see Schmidt III, 2014, pp. 97-99). From the literature that was examined in this chapter (see Table 10), only the studies of Wilkinson (see 2014b) focussed on developing valid weighting factors. Most evaluation methods do not specify the situations that they aim to optimize, and without a specific optimization goal, solutions cannot be validated and valid weighting factors cannot be determined.

Wilkinson's approach is purely quantitative. Such an approach can explain what works in general, but not how it works. Thus, when the numbers change, it is difficult to explain why (e.g. Wilkinson, 2014a, p. 216). Furthermore, when a designer or client wants to prioritize specific aspects of changeability, he or she needs to know more than what works in general. A scenario-based approach does explain how something works. However, the method proposed in this chapter also has its disadvantages: (1) it is very time-consuming; and (2) it requires extensive knowledge about the subject matter. Therefore, the method is probably most suitable for research purposes. However, it can also have a practical use for educational purposes. As mentioned in the Introduction (4.1.), a designer must first learn how to evaluate how well a building performs in terms of expected longevity, before he or she can learn to create long-lasting buildings. By using this evaluation method, it is expected that a designer will learn valuable lessons that will significantly improve his or her future designs, in terms of changeability.

4.4.2. Conclusion

This chapter's aim was to determine the following: how to set up criteria for evaluating a building's changeability? The answer is as follows. Firstly, one must develop scenarios. To develop a scenario, a person must select one of the changes in Table 12 and then ask him- or herself: what could go wrong? Secondly, one must develop design solutions.

To develop a design solution, a person must first select a specific intervention, among those that are permitted (see Figure 29), from Table 11 as the centre of the design solution. Afterwards, one must check the design tactics that are directly associated with this type of intervention and then ask him- or herself: which other design tactics can be beneficial to any aspects of the solution? These results can help both researchers and designers to create scenarios and to develop design solutions to the potential problems described in these scenarios.

CHAPTER

5

How adjustable is the
Environmental Building?

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Chapter 5's purpose

In Chapter 4, a method of evaluating a building's changeability is proposed. Chapter 5's purpose is to develop an initial evaluation of this evaluation method. There are two distinct aspects of design support that can be evaluated (Blessing and Chakrabarti, 2009, p. 37): (1) its application - can the support be used for the task for which it is intended; and (2) its success - does the support have the expected impact. Due to time constraints, the initial evaluation, of this method for evaluating a building's changeability, only focusses on the method's application. Chapter 5's outcome must provide an indication of whether or not specific strengths and weaknesses of the building's design, in relation to the user's changing requirements, can be identified by using the evaluation method proposed in Chapter 4.

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5.1. Introduction

In Chapter 4, a method of evaluating a building's changeability is proposed. This method's aim is to not only grade a building, but to also provide an explanation of what that grade means, i.e. which changes can the building comply with, and which changes can the building not comply with. This may not seem so noteworthy – to explain what an evaluation is based on. However, in this field, a common problem with existing methods is that their numbers are often not or insufficiently backed up by rational explanations (see Schmidt III, 2014, pp. 97-99). Therein lies the value of the proposed method - it should not have this problem. However, does it work?

There are two distinct aspects of the method that can be evaluated (Blessing and Chakrabarti, 2009, p. 37): (1) its application - can the support be used for the task for which it is intended; and (2) its success - does the support have the expected impact. The expected impact is greater longevity; buildings with greater changeability will have greater longevity. However, monitoring the effects, of an intervention, on the lifespan of a building is practically not feasible. The alternative is to test whether or not specific design solutions are beneficial, for the building's users and owners, during specific change scenarios, under various conditions. This approach is theoretically feasible, but it is still very time-consuming. Therefore, this initial evaluation, of the method for evaluating a building's changeability, will only focus on the method's application.

To do so, an existing building is evaluated in terms of adjustability by following the steps described in the method. Adjustability is the first of four changeability levels (see 4.3.1.). Covering only the first changeability level should be enough to get an indication of whether or not specific strengths and weaknesses of the building's design, in relation to the user's changing requirements, can be identified by using the evaluation method. The building that is evaluated is BRE's (Building Research Establishment) Environmental Building. The Environmental Building was completed in 1996 (Feilden Clegg Bradley Studios, n.d.) to demonstrate how to implement various sustainable practices in the built environment (EOF Group, 1995a, p. 1). Since the Environmental Building was a demonstration project, a lot of information about the project has been published. A lot of information of a building is required in order to evaluate its changeability. Therefore, the Environmental Building is both an interesting and accessible subject for the evaluation. The most innovative aspect of this building is the design of its services systems (Bunn, 1997, p. 18). However, the aforementioned innovation was only implemented in the building's main section, i.e. a three storey office block (Herbert, 1998, pp. 87-88). Therefore, only this section of the building will be evaluated.

5.2. Method

5.2.1. Introduction

This chapter's aim is to test whether or not specific strengths and weaknesses of the building's design, in relation to the user's changing requirements, can be identified by using the evaluation method proposed in Chapter 4. To do so, the Environmental Building's adjustability is evaluated by following the steps described in this method. The method comprises five steps: (1) develop scenarios; (2) develop design solution(s) per scenario; (3) assess scenarios' likelihood and severity; (4) establish weighted criteria based on both the scenarios' design solutions and the scenarios' likelihood and severity; and (5) use these weighted criteria to evaluate the building (see Chapter 4, Fig. 27).

5.2.2. Develop scenarios

A scenario describes a causal relation, i.e. an if-this-than-that relation, that contains two primary components: (1) the change; and (2) the mismatch. To develop scenarios, one starts by developing changes. Then, these changes must be linked to mismatches to form scenarios. The changes are drawn from the changeability levels' description (see 4.3.1.), while the mismatches are drawn from literature regarding the physical environment's effect on workers' satisfaction and performance (e.g. Al Horr et al., 2016, p. 385, Fig. 3; Carnevale, 1992, p. 427, Fig. 1; Sundstrom, 1986, p. 80, Fig. 4.3).

5.2.3. Develop design solutions

To develop a design solution, one starts by determining the type of intervention that the solution will centre around. These types of intervention are drawn from the changeability levels' description (see 4.3.1.). Then, design tactics are developed and combined into a design solution. The design tactics are drawn from the following 10 types of design tactics: (1) overdesigned; (2) blank; (3) uniform; (4) diverse; (5) appropriate; (6) undemanding; (7) convenient; (8) robust; (9) unique; and (10) intelligible (see 4.3.2.). During the development of a design solution, one should first consider the inclusion of design tactics that are directly associated with the type of intervention that the solution centres around. Afterwards, the inclusion of other design tactics must also be considered.

5.2.4. Assess likelihood and severity

A scenario's likelihood is determined by both: (1) the change's expected frequency; and (2) the probability that this change, when it occurs, will result in a certain mismatch.

Generally, such statistics are often not recorded. Therefore, estimates will be based on any information that is found, and thus a lot of assumptions will be necessary. Furthermore, a scenario's severity is described by the percentage of productivity decrease that it is associated with. Differences in scenarios' severity are mostly based on the result of five different studies on the relative importance of various determinants on workers' self-rated satisfaction with the physical work environment (see Kim and de Dear, 2013; Leder et al., 2016; O'Neill, 1994; Sakellaris et al., 2016; Veitch et al., 2007).

5.2.5. Evaluate the building

In step 5 of the method, one must evaluate to what degree the design solutions have been implemented. A design solution generally comprises multiple design tactics. Each individual design tactic's implementation will be rated separately. Afterwards, these results are added together into the ratings of design solutions' implementation. This process is termed the Analytic Hierarchy Process (Saaty, 1990). Finally, for the overall evaluation, the rating of each design solution's implementation is multiplied by a weighting factor, that is based on the associated scenario's likelihood and severity, and then the weighted ratings are added together.

5.3. Results

5.3.1. Evaluation criteria

5.3.1.1. Introduction

In the method, the first four out of five steps describe how to set up weighted evaluation criteria. Thus, a significant amount of preliminary work is needed. These elements are dealt with in the following sequence: (1) the changes and their expected frequency; (2) the mismatches and their severity; and (3) the design solutions and their weighting. Furthermore, the probability estimates, i.e. estimates about the probability that a change will result in a certain mismatch, are dealt with in Appendix 3.

5.3.1.2. Changes and their expected frequency

A building's adjustability is its ability to comply with individual-level changes. On the individual level, in an office setting, the reference situation is as follows: person X does work X at workstation X. In this situation, two changes can occur. Firstly, change 1: person X is replaced by person Y while both work X and workstation X stay the same. Three real-life situations will result in such a change: (1) a person voluntarily leaves his/her job; (2) a person involuntarily leaves his/her job; or (3) a person is reassigned to another workstation. In the UK, annual employee turnover is on average about 13% (Martin, 2003, p. 395, Table 1). Therefore, it is assumed that change 1 will occur 15 times per year in a 100-person organization.

Secondly, change 2: work X is replaced by work Y while both person X and workstation X stay the same. Two real-life situations can result in such a change: (1) a person is given another status; or (2) a person is given another function. However, such changes are often accompanied by a change in workstation (1 out of 2 times is assumed) – which would change the nature of the change. In a study of West and Nicholson (1989, pp. 338-340), about 26% of the respondents changed jobs within their organization within the studied timespan of about 15 months. Therefore, it is assumed that change 2 will occur 10 times per year in a 100-person organization.

5.3.1.3. Mismatches and their severity

A mismatch generally means that a building no longer fulfils people's requirements – something is lacking. In Table 14, a ranking is shown in which mismatches are ranked in terms of severity, i.e. according to how much they affect workers' satisfaction with the work environment.

Firstly, thermal comfort, air quality and lighting conditions are equally important factors

rank	mismatch	effect
1	insuf. privacy	-4%
	insuf. ergonomics	-4%
2	insuf. thermal comfort	-2%
	insuf. air quality	-2%
	insuf. lighting conditions	-2%
	insuf. operating space	-2%
3	insuf. closeness	-1%

Table 14. A list of mismatches that are ranked according to how much they affect workers' satisfaction with the work environment. The effect is stated in percentage of productivity decrease.

for workers' satisfaction with the work environment (Sakellaris et al., 2016, Table 4) (cf. Kim and de Dear, 2013, p. 23; Veitch et al., 2007, p. 182, Table 2). Concerning thermal comfort, according to Saari et al. (2006, pp. 1964-1966), a higher temperature than 25°C will result in a productivity decrease of 2% per degree. Concerning air quality, according to Seppänen et al. (2006), a higher ventilation rate will generally result in a 1-3% increase in performance per 10 l/s-person. Concerning visual comfort, in a study of Juslén et al. (2007), higher lighting levels (+400 lux) resulted in a 3% increase in productivity in an industry where the work is visually demanding. Therefore, it is assumed that in general each degree of deviation from a person's optimum, in terms of either thermal comfort, air quality or lighting conditions, will have consequences that are equivalent to a productivity decrease of 2%.

Secondly, the amount of privacy is a more important factor, for workers' satisfaction with the work environment, than thermal comfort, air quality or lighting conditions (Sakellaris et al., 2016, Table 4; Veitch et al., 2007, p. 182, Table 2) (cf. O'Neill, 1994, p. 517, Table 1). Furthermore, ergonomic comfort is also one of the most important factors for workers' satisfaction with the work environment (cf. Kim and de Dear, 2013, p. 23). Concerning privacy, in a study of Jahncke et al. (2013), a noisy room resulted in a 6% productivity decrease specifically for employees whose work involves the processing of new information. Concerning ergonomic comfort, in a study of Robertson (2007), improving an office space with among others ergonomically designed workstations resulted in a 5,5% productivity increase. Furthermore, an even greater productivity increase (10,5%) was achieved by also providing ergonomic training. Therefore, it is assumed that in general each degree of deviation from a person's optimum, in terms

of either the amount of privacy or ergonomic comfort, will have consequences that are equivalent to a productivity decrease of 4%.

Thirdly, in a study of Kim and de Dear (2013, p. 23), the amount of space at occupants' individual workstations was the most important factor for workers' satisfaction with the work environment. However, one of the reasons why this factor was rated so highly is because it is associated with privacy (see Leder et al., 2016, p. 42, Table 6) – more space per worker means that workers are further apart from each other. On the other hand, the amount of personal storage space is also an important factors for workers' satisfaction with the work environment (O'Neill, 1994, p. 517, Table 1) (cf. Veitch et al., 2007, p. 182, Table 2). Therefore, it is assumed that in general each degree of deviation from a person's optimum, in terms of the amount of operating space, will have consequences that are equivalent to a productivity decrease of about 2%.

Finally, the amount of closeness is ranked as the least important factor in Table 14 (cf. Kim and de Dear, 2013, p. 23; O'Neill, 1994, p. 517, Table 1). In an office, there is both a need for privacy and a need for socializing (Haans et al., 2007). For informal interaction to happen, there must first be a chance that people encounter each other – having people both close together and accessible increases this chance. However, for an encounter to become an interaction, privacy is needed (see Fayard and Weeks, 2007, pp. 620-623). Thus, privacy is needed for both solitude purposes and social interaction purposes. Furthermore, office employees generally prefer privacy over accessibility (Sundstrom et al., 1980, p. 114). Therefore, it is assumed that in general each degree of deviation from a person's optimum, in terms of closeness, will have consequences that are equivalent to a productivity decrease of about 1%.

5.3.1.4. Design solutions and their weighting

Scenarios are developed to identify potential problems, and potential problems are identified to determine which design solutions are useful. In Table 15, a list of all scenarios and their weighting is shown. For these scenarios, three different types of design solutions are relevant. Firstly, type 1: a design solution that centres around changing to what extent a capacity of the workstation is used. This type of design solution only comprises a single design tactic: (1) overdesign the capacity (overdesigned). Secondly, type 2: a design solution that centres around changing who uses which type of workstation. This type of design solution comprises the following design tactics: (1) use multiple types of workstations throughout the building (diversity); (2) use workstations that are, besides their type differences, identical in functionality (uniform); and (3) use a surplus of each type of workstation (overdesigned).

scenario	change	mismatch	likelihood	severity	weighting
1	change 1	insuf. privacy	3,00x	0,04%	1,20
2	change 1	insuf. ergonomic comfort	9,38x	0,04%	3,75
3	change 1	insuf. thermal comfort	3,75x	0,02%	0,75
4	change 1	insuf. air quality	1,5x	0,02%	0,30
5	change 1	insuf. lighting conditions	1,83x	0,02%	0,37
6	change 1	insuf. operating space	0,23x	0,5%	1,17
7	change 1	insuf. closeness	3,00x	0,01%	0,30
8	change 2	insuf. privacy	2,00x	0,04%	0,80
9	change 2	insuf. ergonomic comfort	1,36x	0,01%	0,14
10	change 2	insuf. thermal comfort	1,25x	0,02%	0,25
11	change 2	insuf. air quality	1,25x	0,02%	0,25
12	change 2	insuf. lighting conditions	0,10x	0,02%	0,00
13	change 2	insuf. operating space	2x	0,02%	0,40
14	change 2	insuf. closeness	2,22x	0,01%	0,22

Table 15. A list of all scenarios and their weighting. Weighting equals likelihood multiplied by severity multiplied by 10.

Thirdly, type 3: a design solution that centres around switching between pre-established settings. This type of design solution comprises the following design tactics: (1) use pre-established settings (appropriate); (2) use independent settings for each social territory (uniform); (3) use intuitive controls for the settings (intelligible); (4) situate the controls in an ergonomically accessible location (convenient); (5) use controls that do not require a lot of force to operate (convenient); and (6) use controls that do not require a lot of actions to operate (undemanding). Finally, in Table 16, a list of all relevant design solutions and their weightings is shown. In Table 16, there are some scenarios that have two design solutions. Of those design solutions, only the best implemented solution will affect the final score, since a problem only needs to be solved once.

scenarios	design solution	weighting
2	adjustable furniture settings	3,75
1, 8	overdesigned workstations in terms of privacy	2,00
1, 8	diverse workstations in terms of openness	2,00
6, 13	overdesigned workstations in terms of space	1,57
6, 13	diverse workstations in terms of spaciousness	1,57
3, 10	adjustable thermal settings	1,00
4, 11	adjustable ventilation settings	0,55
7, 14	diverse workstations in terms of closeness	0,52
5, 12	adjustable lighting settings	0,37
9	diverse workstations in terms of ergonomics	0,14

Table 16. A list of all relevant design solutions, the scenarios that each design solution is a solution to and the design solutions' weightings.

5.3.2. Evaluating the building

5.3.2.1. Introduction

In Figure 30, an illustration of the Environmental Building's interior is shown in which several of the building's elements are highlighted. Furthermore, in Figure 31, a floor plan of the building's main section is shown. Finally, in Figure 32, an illustration of the top floor's furniture layout is shown. Most of the information, about the Environmental Building, that is presented in this chapter is drawn from six different articles and reports (see Bunn, 1997; Cawthorne, 1997; Herbert, 1998; Ní Riain et al., n.d.; Ní Riain et al., 1999; White et al., n.d.). In the following section, each design solution's implementation is dealt with, except for the two design solutions related to ergonomics. The adjustability of the office chairs and desks will not be evaluated in this chapter. However, for an thorough study on the adjustability of various office chairs, see Helander et al. (1995).

5.3.2.2. Adjustable lighting settings

In terms of lighting settings, the Environmental Building contains three components that are relevant: (1) external motorised fritted-glass louvers; (2) roller blinds; and (3) interior luminaires (see Figure 30). Both the factors on which the implementation of adjustable lighting settings is scored and the score for each factor are shown in Table 17.

Figure 30. An illustration of the building's interior without furniture. The following elements are shown: (1) steel column, 219mm in diameter; (2) raised floor, 1,5m in width; (3) under-floor pipes embedded in the screed, 1,5m in width; (4) peripheral radiator; (5) manually openable windows; (6) external motorised fritted-glass louvers; (7) frosted glass windows which open into a thermal chimney; (8) manually controlled roller blinds; (9) computer operated top openings, openable directly to the occupied space; (10) sinusoidal hollow-core concrete slab; (11) luminaire with both upward and downward light output; (12) duct connected directly to the outside by a computer operated top opening; and (13) duct connected to a thermal chimney by a computer operated top opening.

Concerning the number of settings, firstly, the external louvers can rotate from their vertical position (0°) to 10° beyond their horizontal position (100°) (Cawthorne, 1997, p. 8). When the louvers are set beyond their horizontal position, daylight is reflected from their upper surfaces into the interior. Secondly, roller blinds are manually operable and they can be set at any position between fully open and fully closed. Thirdly, for artificial lighting, there are luminaires in the building that produce both an upward light output (approximately 40%) and a downward light output (approximately 60%) (Bunn, 1997, p. 22). These lights can be dimmed to any value between 0 and 100%. Therefore, the number of lighting settings is given a score of 5 out of 5.

Figure 31. A floor plan of the first floor of the building's main section without furniture or partitioning (scale is 1 : 300). The following elements are shown: (1) viewpoint on which Figure 30 is based; (2) service zone / "central spine" (EOF Group, 1995b); (3) under-floor pipes embedded in the screed; (4) hallway ventilation through hollow-core concrete ducts; (5) direct ventilation of the occupied space through top openings; and (6) thermal chimney.

Figure 32. An illustration of the top floor's furniture layout (scale is 1 : 300). This illustration is based on photos made (on the 11th of April 2019) and provided by Ben Cartwright from BRE.

Concerning the independence in exercising control, the lights can be operated per individually fitting (Herbert, 1998, p. 89), and the roller blinds are operable per window. Furthermore, the louvres in front of the south-facing façade are controlled for each section (4,5m) in between two chimneys (see photos at <https://www.coltinfo.co.uk/case-studies/bre-building-16.html>). Therefore, the independence in exercising control is given a score of 4 out of 5.

Concerning the intuitiveness of controls, two factors are important: (1) the type of feedback provided by the system; and (2) the independence of functions. Firstly, for all three lighting components, i.e. external louvers, roller blinds and luminaires, one can instantly see the effects of exercising control. Secondly, controls are more simple when each control affects a single function. Typically, the functions of preventing glare and obstructing incoming daylight are dependent in a building, i.e. glare cannot be stopped without obstructing incoming daylight. However, the Environmental Building’s louvers are coated with a translucent white coating (37% transmittance) to keep a diffused form of natural illumination when the louvers are fully closed during the day (Cawthorne, 1997, p. 11, 13). Therefore, glare can be prevented without obstruct all incoming daylight. Furthermore, incoming daylight typically both lights up and heats up the building. However, in the Environmental Building, the thermal energy of incoming daylight is first temporarily stored in the exposed-concrete ceiling. Thus, one can allow daylight to light up the space without having to worry about it heating the space up as well. Therefore, the intuitiveness of controls is given a score of 5 out of 5.

Concerning the ease of operating, both the position of the louvres and the luminaires’ light output can be changed via handheld controls (Herbert, 1998, p. 89; Ni Riain et al., n.d., p. 5). Furthermore, the roller blinds can be operated manually. Therefore, the ease of operating is given a score of 5 out of 5. Overall, the implementation of adjustable lighting settings is given a score of 4,75 out of 5.

factors	score
number of settings	5 / 5
independence in exercising control	4 / 5
intuitiveness of controls	5 / 5
ease of operating	5 / 5

Table 17. A list of both the factors on which the implementation of adjustable lighting settings is scored and the score for each factor.

5.3.2.3. Adjustable temperature settings

In terms of temperature settings, the Environmental Building contains four components that are relevant: (1) working-height windows; (2) top openings; (3) under-floor pipes; and (4) peripheral radiators (see Figure 30). Both the factors on which the implementation of adjustable temperature settings is scored and the score for each factor are shown in Table 18.

Concerning the number of settings, firstly, about one-third of the working-height windows are openable, and they can only be opened by turning them inward – not by tilting them inward (see https://fcbstudios.com/images/Raw/Feilden_Clegg_Bradley_Studios--Environmental_Office_BRE-Garston-Elevation.jpg). Secondly, the top openings are computer controlled and they can be tilted at any position between 0 and 100% open (see Bunn, 1997, p. 20; Ni Riain et al., 1999, p. 315). Thirdly, under-floor pipes can either actively heat or cool the occupied space, depending on the type of water run through them. For cooling the system of under-floor pipes draws cool water from a 75m-deep borehole (Ni Riain et al., 1999, p. 310). This feature was designed to reduce the peak internal temperatures by 2°C (Ni Riain et al., n.d., p. 5). For heating the system uses water heated in a boiler room in the building's east wing (Bunn, 1997, p. 19, 21). Finally, the peripheral radiators can be set at different temperatures by turning the radiator valves. Therefore, the number of temperature settings is given a score of 5 out of 5.

Concerning the independence in exercising control, each peripheral radiators can be operated individually. Furthermore, over the long axis, each section that includes under-floor pipes is placed in between two other sections without any active heating or cooling system (see Figure 31). Thus, temperature is controlled by this system in three-meter-wide sections. Finally, an openable window, i.e. either a working-height window or a top opening, is present at every section of 1,5m in width. Therefore, the independence in exercising control is given a score of 4 out of 5.

Concerning the intuitiveness of controls, two factors are important: (1) the type of feedback provided by the system; and (2) the independence of functions. Firstly, in the Environmental Building, the under-floor pipes are controlled by a building management system (Herbert, 1998, p. 89). Users cannot control this element directly, they can only exercise control over it by overriding the local temperature settings (Ni Riain et al., n.d., p. 5). However, for the working-height windows, the top openings and peripheral radiators, one can instantly feel or hear the effects of exercising control. Secondly, controls are more simple when each control affects a single function. In the Environmental Building, one can both increase or decrease the temperature without

negatively affecting other functions. However, the function of the windows to cool the interior space cannot be used without interfering with another one of its functions, i.e. to keep out external noise. Therefore, the intuitiveness of controls is given a score of 4 out of 5.

Concerning the ease of operating, both the local temperature settings and the top openings can be operated via handheld controls. Furthermore, both the working-height windows and peripheral radiators can be operated manually. Therefore, the ease of operating is given a score of 5 out of 5. Overall, the implementation of adjustable temperature settings is given a score of 4,5 out of 5.

factors	score
number of settings	5 / 5
independence in exercising control	4 / 5
intuitiveness of controls	4 / 5
ease of operating	5 / 5

Table 18. A list of both the factors on which the implementation of adjustable temperature settings is scored and the score for each factor.

5.3.2.4. Adjustable ventilation settings

In terms of ventilation settings, the Environmental Building contains four components that are relevant: (1) working-height windows; (2) top openings that open directly into the occupied space; (3) top openings that connect the outside air to hollow-core concrete ducts which guide the fresh air directly into the corridor zone; and (4) top openings that connect thermal chimneys to the hollow-core concrete ducts (Ni Riain et al.,1999, pp. 314-315) (see Fig 30). Both the factors on which the implementation of adjustable ventilation settings is scored and the score for each factor are shown in Table 19.

Concerning the number of settings, firstly, about one-third of the working-height windows are openable, and they can only be opened by turning them inward – not by tilting them inward (see https://fcbstudios.com/images/Raw/Feilden_Clegg_Bradley_Studios--Environmental_Office_BRE-Garston-Elevation.jpg). Secondly, all top openings are computer controlled and they can be tilted at any position between 0 and 100% open (see Bunn, 1997, p. 20; Ni Riain et al.,1999, p. 315). Thirdly, the thermal chimneys are meant to compensate for a lack of wind-driven air flow by generating a stack-driven air flow. However, each tower is also equipped with an internal propeller

factors	score
number of settings	5 / 5
independence in exercising control	5 / 5
intuitiveness of controls	5 / 5
ease of operating	5 / 5

Table 19. A list of both the factors on which the implementation of adjustable ventilation settings is scored and the score for each factor.

fan for when the stack effect is also not sufficient (Bunn, 1997, p. 20). Therefore, the number of ventilation settings is given a score of 5 out of 5.

Concerning the independence in exercising control, at both the north-facing and south-facing façades, there is an openable window present, i.e. either a working-height window or a top opening, at every section of 1,5m in width. Furthermore, the hollow-core concrete ducts are used as unobstructed pathways to guide fresh air directly into the corridor zone. In the corridor, there are concrete ducts connected to the outside for every 3m of corridor space. This system can theoretically facilitate the spaces on both sides of the corridor. However, since the northern section of the building is not directly open to the corridor space – it contains cellular offices (Bunn, 1997, p. 18) – the system will mainly facilitate the southern section. In other words, over the building's short axis, it can be divided into three individual control areas. Therefore, the independence in exercising control is given a score of 5 out of 5.

Concerning the intuitiveness of controls, two factors are important: (1) the type of feedback provided by the system; and (2) the independence of functions. Firstly, for the working-height windows and some of the top openings, one can instantly see and feel the effects of exercising control. However, these effects are less apparent for the top openings connected to the concrete duct system. Secondly, controls are more simple when each control affects a single function. Incoming outdoor air typically affects both the ventilation and the temperature within the building. However, in the Environmental Building, when only the concrete duct system is used to bring in fresh air, the incoming air will have less of an effect on the temperature; heat is exchanged between the incoming air and the concrete mass that tempers any fresh air before entering the occupied space. Furthermore, by using the concrete duct system to bring in fresh air, as opposed to conventional windows, it is more difficult for external noise to get into the

building. Therefore, the intuitiveness of controls is given a score of 5 out of 5.

Concerning the ease of operating, the top openings can be operated via handheld controls (Ni Riain et al., n.d., p. 5). Furthermore, the working-height windows can be operated manually. Therefore, the ease of operating is given a score of 5 out of 5. Overall, the implementation of adjustable ventilation settings is given a score of 5 out of 5.

5.3.2.5. Overdesigned workstations in terms of space

In the Environmental Building, on the top floor, there are three types of workstations: (1) the open-office workstation of 3,6m²; (2) the open-office workstation of 4,8m², with filling cabinet; and (3) the private office of 12,5m² (see Figure 32). In the open-office section, workstations are grouped in u-shaped sets of two. At minimum, this set-up (without circulation space) requires 2,3m² of space per workstation (see Panero and Zelnik, 1979, p. 180). In addition, at least 650mm (or in this case 1m²) of clear space is needed to be able to walk behind a workstation (Pheasant, 2003, p. 51). However, for a wheelchair user to be able to turn around, this clear space must be at least 1600mm (or in this case 2,6m²) (see Steinfeld et al., 2010, p. 65, Fig. 8). Furthermore, according to Neufert and Neufert (2000, p. 346), in an average organization, roughly 30% of the non-managerial workers require a workspace of 3,6 to 4,6m² – the rest of the workers need more space. Thus, the Environmental Building's smallest type of workstation is using its operating space to the fullest. Therefore, the implementation of overdesigned workstations, in terms of space, is given a score of 1 out of 5.

5.3.2.6. Diverse workstations in terms of spaciousness

The Environmental Building, on the top floor, contains the following workstations: (1) 26 open-office workstations of 3,6m²; (2) 16 open-office workstations of 4,8m², with filling cabinet; and (3) 7 private offices of 12,5m² (see Figure 32). Both the factors on which the implementation of diverse workstations, in terms of spaciousness, is scored and the score for each factor are shown in Table 20.

Concerning the use of multiple types, in terms of size, there are two types of open-office workstations and there is one type of private office workstation. Therefore, the use of multiple types is given a score of 3 out of 5. Concerning uniform functionality, all larger open-office workstations are located directly next to the corridor zone (see Figure 32). Thus, in comparison to the smaller open-office workstations, the larger ones do not have any access to a window. Otherwise, they are both practically identical in functionality. Therefore, uniform functionality is given a score of 4 out of 5.

Concerning the surplus of workstations, as previously mentioned, in an average organization, roughly 30% of the non-managerial workers require a workspace of 3,6 to 4,6m² – the rest of the workers need more space (Neufert and Neufert, 2000, p. 346). Furthermore, according to Blau (1970, p. 211), about 15% of a 100-person organisation comprises managerial personnel. In the Environmental Building, on the top floor, 14% of the workstations are private offices. Furthermore, 62% of the open-office workstations are smaller workstations, i.e. workstations of 3,6m². Thus, in the Environmental Building, there is not a surplus of larger workstations. Therefore, the surplus of workstations is given a score of 1 out of 5. Overall, the implementation of diverse workstations, in terms of spaciousness, is given a score of 2,67 out of 5.

factors	score
the use of multiple types	3 / 5
uniform functionality	4 / 5
the surplus of workstations	1 / 5

Table 20. A list of both the factors on which the implementation of diverse workstations, in terms of spaciousness, is scored and the score for each factor.

5.3.2.7. Overdesigned workstations in terms of privacy

In terms of privacy, there are four basic settings: (1) having both acoustic and visual privacy, e.g. private office; (2) having visual privacy, but not acoustic privacy, e.g. high screens; (3) having acoustic privacy, but not visual privacy, e.g. a glass box; and (4) not having either acoustic or visual privacy, e.g. open space. In the Environmental Building, on the top floor, 86% of the workstations are unscreened open-office workstations. Therefore, the implementation of overdesigned workstations, in terms of privacy, is given a score of 1 out of 5.

5.3.2.8. Diverse workstations in terms of openness

Both the factors on which the implementation of diverse workstations, in terms of openness, is scored and the score for each factor are shown in Table 21. Concerning the use of multiple types, in terms of openness, there are two types of workstations: (1) the open-office workstation; and (2) the private-office workstation. Therefore, the use of multiple types is given a score of 3 out of 5. Concerning uniform functionality, all private-office workstations are significantly larger than the open-office workstations,

i.e. either 2,6 or 3,5 times as large. Otherwise, they are both practically identical in functionality. Therefore, uniform functionality is given a score of 2 out of 5.

Concerning the surplus of workstations, as previously mentioned, about 15% of a 100-person organisation comprises managerial personnel (Blau, 1970, p. 211). Furthermore, in the Environmental Building, on the top floor, 14% of the workstations are private offices. Thus, in the Environmental Building, there is not a surplus of more enclosed workstations. Therefore, the surplus of workstations is given a score of 1 out of 5. Overall, the implementation of diverse workstations, in terms of openness, is given a score of 2 out of 5.

factors	score
the use of multiple types	3 / 5
uniform functionality	2 / 5
the surplus of workstations	1 / 5

Table 21. A list of both the factors on which the implementation of diverse workstations, in terms of openness, is scored and the score for each factor.

5.3.2.9. Diverse workstations in terms of closeness

Alexander et al. (1977, pp. 610-613) and Habraken (1998, pp. 134-179) both described a similar phenomenon which the former referred to as an “*intimacy gradient*” and the latter as “*territorial hierarchy*”. This phenomenon is concerned with a space being perceived as more private when it is more remote and less directly accessible (e.g. through another space). Thus, a space that is perceived as closer by is less repellent for people, and thus such a space is more likely to have chance encounters. However, it is argued that this feature cannot be overdesigned; when all office space is open, social considerate behaviour will hinder any social interaction - as it would otherwise disturb people who are trying to concentrate. This is probably why people in an open-plan office have a higher need for socializing (see Haans et al., 2007). Therefore, the only design solution to changing requirements in terms of closeness is diverse workstations. In Table 22, both the factors on which the implementation of diverse workstations, in terms of closeness, is scored and the score for each factor are shown. Concerning the use of multiple types, in terms of closeness, there is not much diversity as is shown in Figure 33. Within the open space, there are two visual breaks or subdivisions, i.e. between the corridor and the open spaces and between the open-office space and the

kitchen area. However, all rooms and separate areas are directly accessible from the corridor space. Therefore, the use of multiple types is given a score of 1 out of 5. Without there being multiple types, no one can move from one type of workstation to another, regardless of the implementation of the other factors. Therefore, overall, the implementation of diverse workstations, in terms of closeness, is given a score of 1 out of 5.

factors	score
the use of multiple types	1 / 5
uniform functionality	-
the surplus of workstations	-

Table 22. A list of both the factors on which the implementation of diverse workstations, in terms of closeness, is scored and the score for each factor.

Figure 33. The remoteness of spaces of the Environmental Building’s top floor. In this figure, a box represents a separate space, and a line between two boxes represents a subdivisions between those two spaces (e.g. a door or a visual break). Furthermore, the number within each box indicates the box’s degree of remoteness.

5.3.2.10. Final score

In Table 23, an overview of the score and weighting of each design solution’s implementation is shown. The final score is calculated by: (1) multiplying each score by the weighting factor; (2) adding the weighted scores together; and (3) comparing this number to the highest possible score. Overall, the Environmental Building’s adjustability is given a score of 17,72 out of 30,05, i.e. 2,95 out of 5.

design solution	score	weighting
adjustable furniture settings	-	3,75
overdesigned workstations in terms of privacy	1,00	2,00
diverse workstations in terms of openness	2,00	2,00
overdesigned workstations in terms of space	1,00	1,57
diverse workstations in terms of spaciousness	2,67	1,57
adjustable thermal settings	4,50	1,00
adjustable ventilation settings	5,00	0,55
diverse workstations in terms of closeness	1,00	0,52
adjustable lighting settings	4,75	0,37
diverse workstations in terms of ergonomics	-	0,14

Table 23. A list of all relevant design solutions, the design solutions' scores and the design solutions' weightings. The final score is only based on the design solutions that are presented in black text in this figure, those that are presented in grey text are not taken into account.

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5.4. Discussion and conclusion

5.4.1. Discussion

As shown in Table 23, the Environmental Building has the ability to comply with changing requirements of the individual in terms of indoor climate conditions. However, it lacks the ability to comply with changing requirements of the individual in terms of space, privacy and interaction. Overall, this resulted in a score of 2,95 out of 5. The score itself is not very important; it is based on 22 estimates (2 expected frequency estimates, 12 probability estimates and 8 severity estimates) that are all certainly not perfectly accurate.

More importantly however, the use of this method resulted in clear improvement points. Furthermore, the improvement points match expectations. As mentioned in the introduction (5.1.), the most innovative aspect of this building was the design of its services systems – that was the design team’s main focus (see EOF Group, 1995a). Therefore, it is not surprising that the building is mainly able to comply with changing requirements of the individual in terms of indoor climate conditions, instead of other types of changing requirements.

5.4.2. Conclusion

This chapter’s aim was to evaluate the application of the method of evaluating a building’s changeability, that has been proposed in Chapter 4. As has been demonstrated in this chapter, by using this method, specific strengths and weaknesses of the building’s design in relation to the user’s changing requirements can be identified. Furthermore, by following this method, an assessment is made of the significance of each strength and weakness. In other words, the use of this method will result in clear improvement points. However, the method also has its disadvantages, especially in terms of practicality: (1) it is very time-consuming; and (2) it requires extensive knowledge about the subject matter. The method is very elaborate in nature. However, a lot of the information that is needed in such an analysis can be carried over from one analysis to another, especially when a building with a similar function is analysed in the subsequent analysis, e.g. change scenarios, changes’ likelihood, probability estimates and mismatches’ severity. Thus, the method works as intended. However, it is not yet practically viable. First, the method must be developed further through repeated use.

CHAPTER

6

Discussion and conclusion.

6.1. Discussion

6.1.1. Introduction

In this discussion section, three elements of this dissertation are reflected upon: (1) the methods for setting up a classification, that have been used in this dissertation; (3) the scientific contribution of this dissertation; and (4) the practical relevance, or utility, of the results.

6.1.2. Classification

The majority of the methods used in this dissertation, Structured Analysis, Analytic Hierarchy Process and the Constant Comparative Method, have the same purpose: to set up a classification. A classification can be used as a representation of knowledge - it is “*a way of seeing*” (Kwasnik, 1999, p. 46). As such, a classification is “...*useful in communication and in generating a fresh cycle of exploration, comparison, and theorizing*” (Kwasnik, 1999, p. 24). Setting up a classification is such a fundamental part of science that the process is often not explicitly explained. This dissertation also contains multiple classifications of which is not explained how they came to be. However, the most important classifications, in this dissertation, were developed according to a formal method.

The method that differs most from the other methods, that have been used for setting up a classification in this dissertation, is the Constant Comparative Method. In Chapter 4 this difference was described as using a bottom-up approach, instead of a top-down approach. A classification is composed of two parts: the concepts; and the structure. The top-down approach starts with the development of a logical structure, while the bottom-up approach starts with the development of valid concepts. At the beginning of this research project, the author had assumed that it is generally preferable to prioritize the development of a classification's structure over its concepts. A classification's structure determines its information density (see Kwasnik, 1999); information that is associated with the classification structure applies to all of its concepts, while information that is associated with a concept, within the classification, only applies to the particular concept. The results of this dissertation confirm the author's initial assumption: (1) the top-down approach results in a more developed structure, while the bottom-up approach results in more developed concepts; and (2) a classification with a more developed structure is more comprehensible, than a classification with more developed concepts, due to its greater information density. This dissertation's classification into types of design tactics is more difficult to communicate than the other classifications -

the amount of text needed to explain it is a clear sign of this.

However, the more structure-focused classification approach mostly works for well-defined, or well-definable, topics. For ambiguous topics, like the ability to comply with future change, it is very difficult, and may even be misleading, to define the topic through a relatively narrow structure, instead of the broad range of underlying concepts. In hindsight, the Constant Comparative Method was the appropriate method to set up a classification into types of design tactics, despite the more elaborate nature of the results.

6.1.3. Scientific contribution

This dissertation's scientific novelty lies in the combination of its topic, goal and approach. Regarding the topic, the topic of this dissertation is broader in comparison to numerous similar studies. Much of the research to date only, or primarily, focussed on the physical alterability of the building fabric (Heidrich et al., 2017, p. 294). The topic of changeability however, comprises both the topic of adaptability, i.e. a building's ability to comply with changes through physical alterations to the building fabric; and (2) the topic of flexibility, i.e. a building's ability to comply with changes without physical alterations to the building fabric. Previous results of evaluation research, in relation to the relatively narrower topic of adaptability, also seem more advanced (e.g. see Schmidt et al., 2014), in comparison to those related to the relatively broader topic of changeability. Presumably this is the result of both the topic's smaller scope and the topic's greater popularity.

Regarding the goal, the goal of this dissertation was to develop a method that facilitates the evaluation of the topic as a whole. Much of the research to date mainly focussed on identifying all the relevant elements, i.e. factors, indicators or strategies (e.g. Halvitigala and Reed, 2015; Hassanain, 2006; Remøy and van der Voordt, 2014). However, to evaluate the topic as a whole requires not only knowledge about the relevant elements, but also knowledge about the relations between them. In the literature, there are some results that hint at the importance of individual indicators in relation to each other. Some studies, including this one (see Table 13), counted the number of times that an indicator or strategy was mentioned in the literature (see Heidrich et al., 2017, p. 293; Schmidt III, 2014, p. 83, 86). Schmidt III (2014, pp. 244-245) also counted the number of times that an indicator or strategy was either explicitly mentioned or implied during interviews with experts. Pinder et al. (2013, p. 448) ranked strategies in terms of both certainty of benefits and investments costs. Furthermore, Ross et al. (2016, pp. 423-424) asked experts, through a survey, to quantify the relative effectiveness of indicators

and strategies. However, from the literature that was examined (see Table 10), only the studies of Wilkinson (see 2014b) focussed on developing valid weighting factors.

Regarding the approach, Wilkinson's approach is purely quantitative. Such an approach can explain what works in general, but not how it works. Wilkinson's approach is referred to as the black box approach, i.e. an approach which primarily focusses on the design solutions and the resulting impact. In contrast to the black box approach, the white box approach primarily focusses on the "*mechanisms*" that describe how and why certain design solutions have an impact (see Astbury and Leeuw, 2010). This research's main contribution is that it provides a method for unpacking the black box of design for change. The whole reason for unpacking the black box is that it enables validation.

Validation is the main problem of the black box approach. How can you know for certain whether or not a design solution has a positive effect on a building's lifespan without monitoring this effect? Wilkinson (see 2014b) circumvented this problem by focussed on a different resulting impact: the number of adaptation occurrences. However, more adaptation occurrences are not necessarily beneficial to a building's lifespan. More adaptation occurrences may indicate that the building is highly adaptable, or it may indicate that the building was highly in need of adaptation. The white box approach solves this problem as follows: you know for certain, whether or not a design solution has a positive effect on a building's lifespan, by understanding how, to what extent and in which situations, each design solution contributes to prolonging the use period of a building, and by validating this understanding. The downside of the white box approach is that the task of both identifying and testing all mechanisms is a seemingly insurmountable amount of work. For example, Chapter 5 shows how much work can go into identifying and prioritizing mechanisms. However, it is a way forward, specifically for science.

6.1.4. Practical relevance

Evaluation research is similar to fundamental research; the primary difference between the two is that evaluation research is concerned with "*utilization*" (Vedung, 2004, p. 118) - the research output must be usable. In design research terminology one would say that evaluation research, similar to fundamental research, has a strong focus on understanding. However, unlike fundamental research, evaluation research also has the goal to create support to help improve the situation or process. In terms of utilization, a distinction can be made between two types of uses: "*instrumental use*"; and "*conceptual use*" (Vedung, 2004, p. 119). For an evaluation to have an instrumental use, it must

directly result in specific actions, i.e. the result must describe the most efficient means to reach the indicated goal. An evaluation with a conceptual use does not result in specific actions; it informs - helps to understand - and shapes one's attitude towards the issue, but it does not trigger any specific actions.

What is the use of the evaluation method presented in this dissertation? The evaluation method is composed in a step-by-step manner, in which of each step is specified what the required input and output is (see Figure 27). This is a characteristic of an instrumental method. However, what is missing, for the method to be truly instrumental, is a comprehensive description of how to execute each of these steps. Some tools have been developed to support the execution of the method's first two steps, but these tools have a conceptual use. Furthermore, in Chapter 5 is demonstrated how the method, and its tools, can be used to carry out an evaluation that has an instrumental use. However, to do so involves more than simply following instructions. During the evaluation method's development, instrumental use was strived for, but not to the extent that concessions in the topic's complexity were permitted. As a result, the evaluation method's use can not be classified, in its entirety, as instrumental and should thus be seen, at this stage, as conceptual.

The evaluation methods used in practice should remain practical. Therefore, the evaluation method presented in this dissertation is not an example of what they should become. Methods, such as the one presented in this dissertation, should be used to develop a better understanding of the various mechanisms that describe how and why certain design solutions have an impact. Then, this understanding must first be tested. After which, the more practical evaluation methods can be improved based on this improved, and validated, understanding of the workings of design solutions.

Future research should focus more on validating the workings of design solutions in relation to design for change. A nice example of such research is a study of Gijsbers (2011, pp. 143-162), in which he studied the density at which a column grid starts to hinder the designer in developing a suitable floorplan. In the future, researchers should be able to substantiate, with rational explanations that have also been tested, why certain design solutions are more important than others, for the changeability of a specific building. This dissertation's outcome shows how these rational explanations can be developed. The next step is to develop and test them.

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6.2. Conclusion

6.2.1. Introduction

This research aimed to both understand design and to create support to help improve design, specifically regarding the topic of design for change in relation to sustainable resource usage. This dissertation aimed to increase understanding regarding the overall subject matter by gaining: (1) an initial understanding of the topic of building longevity; (2) a review-based understanding of the topic of changeability; and (3) a comprehensive understanding of the topic of resource depletion. Furthermore, this dissertation aimed to set up support regarding the overall subject matter by developing: (1) initial support for the topic of resource depletion; and (2) comprehensive support for the topic of changeability. Lastly, this dissertation includes an initial evaluation of the design support that has been developed for the topic of changeability.

6.2.2. Understanding

In Chapter 2, a model is presented (see Figure 2) that describes how the process of using resources works, and why this process works the way it does. Based on this model, five intervention areas have been identified: (1) material inputs to manufacturing; (2) process inputs to manufacturing; (3) material inputs to operations; (4) process inputs to operations; and (5) products' longevity. In this model, an intervention area is an area in which a change, or "*intervention*" if it is a conscious change, affects the size of the problem of resource depletion. Thus, a change in one of the intervention areas can either mitigate or aggravate the problem of resource depletion. This dissertation focusses specifically on the intervention area of longevity. To make sure that an intervention in the area of longevity actually contributes towards mitigating the problem of resource depletion, one must examine if, and how, these interventions affect the other intervention areas. The understanding of the topic of resource depletion, gained in Chapter 2, supports this process.

In Chapter 3, a first indication of to what extent a building's longevity is determined by its design is presented. In a way Chapter 3 fulfils the role of devil's advocate - does a changeable design in buildings even matter? Conclusion: for residential buildings it might not matter. Households are significantly more flexible than large organizations; moving is relatively easy for a small family. Furthermore, when a house is a scarce commodity, it is less likely to be demolished prematurely. However, Chapter 3 lacks the evidence to confidently support this statement. What can be stated with confidence however, is that a changeable design has a greater impact on the longevity of non-

residential buildings, compared to the impact on the longevity of residential buildings. The understanding of the topic of longevity, gained in Chapter 3, contributes to a more valid assessment of changeability's contribution towards mitigating the problem of resource depletion.

In Chapter 4, a list is presented (see Table 13) of the types of design tactics of changeability. These design tactics can be used to develop design solutions to potential problems of future change. Such a list is not new - many researchers have developed their own list, and how the topic is categorized is partly dependent on personal preference. The main reason why another list has been developed, in this research, is the following: for similar, already existing, lists, it was not exactly clear on what information the categorizations were based on. Therefore, there was no way to verify whether or not these lists were comprehensive. In this dissertation, all the information that the categorization of design tactics is based on is included in Appendix 2.

6.2.3. Support

In Chapter 2, intervention areas, in relation to the problem of resource depletion, are ranked according to how much of a change can be expected from interventions in the area. Longevity was ranked as the second most effective intervention area. So, it is a very significant solution area for the problem of resource depletion. Furthermore, the outcome of Chapter 2 shows that interventions in longevity can be prioritized over interventions in the manufacturing phase. This also means that, if they are done right, solutions meant to prolong the use period of products, parts and buildings will contribute towards mitigating the problem of resource depletion, even if they require a greater resource input in the manufacturing phase.

In Chapter 4, both a scenario-based method of evaluating a building design's changeability (see Figure 27), and the support needed to use this method, is presented. A list of general changes (see Table 12) has been set up to support the development of scenarios, that are, in turn, meant to identify potential problems. Furthermore, to support the development of design solutions to these potential problems the following things have been set up: (1) a list of types of design tactics (see Table 13); (2) a categorization of changeability into changeability levels (see Figure 29); and (3) a categorization of various types of adjustments into different scales (from small-scale to extra-large-scale) (see Table 11). The support for the topic of changeability, that has been developed in Chapter 4, helps to: (1) specify optimization goals, in relation to future change, that are relevant for a specific situation, i.e. building plus context; (2) determine key performance indicators, in relation to these specified optimization goals;

and (3) determine valid weighting factors for each of those indicators.

6.2.4. Evaluation

In Chapter 5, an initial evaluation of the method of evaluating a building's changeability is presented. The method's application was evaluated - thus, can the method be used for the task for which it is intended. The evaluation shows that specific strengths and weaknesses of the building's design in relation to the user's changing requirements can be identified by using this method. Furthermore, by following the method, an assessment is made of the significance of each strength and weakness.

6.2.5. Main research question

This dissertation's main research question was: 'How can a building design's changeability, and the effect of this changeability on the problem of resource depletion, be evaluated?'. To what extent has this question been answered? First, rules of thumb have been developed to help prioritise interventions in relation to the problem of resource depletion. Second, a method of evaluating a building's changeability has been developed. Third, conceptual tools have been developed to help use the evaluation method. Fourth, how to use the method, and its tools, to carry out an evaluation, that has an instrumental use, has been demonstrated through an example. However, the evaluation method, at this stage, is not entirely instrumental; it lacks a comprehensive description of how to execute each of the steps, instead conceptual tools have been developed to help the execution of these steps. Thus, this dissertation provides an answer to the main research question, however this answer is still somewhat open for interpretation.

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Appendix 1.

Cases' information.

No.	year	address	type of house	unit size	project size (in units)	width (mm)	length (mm)	ceiling height main floor	ceiling height first floor
1	1900	Pater brugmanstraat 3	row	284m ²	15	6000	13200	3600 mm	3300 mm
2	1902	Jan van Galenstraat 28	row	97m ²	8	5600	7900	3000 mm	3000 mm
3	1911	Weurtseweg 228	row	70m ²	41	4600	6600	3000 mm	2500 mm
4	1913	Jan van Galenstraat 33	row	110m ²	21	5200	7800	3100 mm	2500 mm
5	1913	Sumatrastraat 8	row	220m ²	8	6300	9500	3500 mm	3500 mm
6	1922	Maasplein 18	row	83m ²	68	4820	7160	2780 mm	2480 mm
7	1923	Anna van Bijnsstraat 8	row	81m ²	54	4380	7160	2700 mm	2400 mm
8	1923	Beetsplein 31	row	96m ²	139	4380	7160	2780 mm	2400 mm
9	1930	Sweelinckstraat 57	row	80m ²	75	5130	6760	2700 mm	2400 mm
10	1938	Distelstraat 24	row	84m ²	88	4630	6360	2700 mm	2500 mm
11	1939	Leeuwstraat 57	row	114m ²	66	5270	8360	2750 mm	2400 mm
12	1940	Lingestraat 19	row	73m ²	126	4780	7060	2730 mm	2500 mm
13	1948	Klaverstraat 15	row	90m ²	101	5480	6960	2700 mm	2500 mm
14	1949	Corduenerstraat 64	row	102m ²	83	5480	6960	2700 mm	2500 mm
15	1950	Barneveldse Beekstraat 9	row	89m ²	86	5500	7200	2700 mm	2400 mm
16	1951	Duindoornstraat 67	row	74m ²	190	5370	6830	2635 mm	2405 mm
17	1956	Kaaplandstraat 14	row	95m ²	77	5680	6690	2600 mm	2400 mm
18	1957	Albertus Magnusstraat 14	row	120m ²	81	6100	7710	2620 mm	2400 mm
19	1959	Edisonstraat 24	row	87m ²	468	5870	6520	2600 mm	2450 mm
20	1960	Kanunnik Pelsstraat 34	row	111m ²	294	5930	7360	2600 mm	2400 mm
21	1965	Cimbaalstraat 53	row	113m ²	194	5800	8050	2600 mm	2400 mm
22	1965	Groen van Prinstererstraat 35	row	83m ²	244	5940	6840	2600 mm	2400 mm
23	1967	Aldenhof 2303	row	113m ²	423	5910	7500	2600 mm	2400 mm
24	1973	Tolhuis 4304	row	114m ²	290	4460	12840	2600 mm	2400 mm
25	1977	de Voorstenkamp 1021	row	115m ²	244	5220	8400	2600 mm	2400 mm
26	1978	Zwaluwstraat 72	row	96m ²	215	5220	8240	2600 mm	2850 mm
27	1981	Horstacker 2108	row	104m ²	90	5600	7800	2600 mm	2400 mm
28	1982	Hillekensacker 2122	row	113m ²	115	5500	7700	2600 mm	2400 mm
29	1990	Harriët Freezerlaan 48	linked double	169m ²	42	5500	9000	2470 mm	2470 mm
30	1996	Albert Schweitzerlaan 100	linked double	148m ²	56	5400	9500	2440 mm	2440 mm
31	1997	Keplerstraat 141	row	122m ²	93	5170	9100	2440 mm	2440 mm
32	2000	Bellefleurstraat 36	linked double	151m ²	144	5480	9910	2440 mm	2440 mm
33	2001	Akkerwinde 17	row	118m ²	89	5480	8610	2440 mm	2440 mm
34	2005	Weefgewichtstraat 58	row	162m ²	62	5450	10500	2670 mm	2670 mm
35	2005	Tegulastraat 8	row	111m ²	78	5150	9580	2570 mm	2570 mm
36	2006	Pink Floydstraat 84	row	101m ²	94	5100	9400	2450 mm	2450 mm
37	2008	Vrouwe Udasingel 159	row	175m ²	115	5400	9980	2700 mm	2700 mm

No.	year	address	type of house	unit size	project size (in units)	width (mm)	length (mm)	ceiling height main floor	ceiling height first floor
38	1901	Goorstraat 72	two-family	191m ²	10	5700	8100	3000 mm	-
39	1907	Graafsedwardsstraat 19	two-family	108m ²	8	5650	8550	3020 mm	-
40	1909	Van den Havestraat 36	two-family	103m ²	11	5700	9300	3000 mm	-
41	1912	Parkweg 72	two-family	130m ²	5	7200	11330	3200 mm	-
42	1925	Maerlantstraat 31	two-family	84m ²	34	4280	7060	2780 mm	-
43	1927	Van 't Santstraat 31	two-family	91m ²	98	5010	7060	2700 mm	-
44	1934	Hengstdalseweg 73	two-family	121m ²	21	5400	7760	2710 mm	-
45	1934	Marsstraat 9	two-family	69m ²	21	5400	8700	2750 mm	-
46	1939	Sterreschansweg 13	block of flats	83m ²	42	8020	11500	2900 mm	-
47	1950	Barneveldse Beekstraat 10	two-family	100m ²	78	5950	7200	2700 mm	-
48	1951	Vogelkersstraat 38	block of flats	50m ²	251	6730	8090	2830 mm	-
49	1953	Wolfstraat 138	block of flats	74m ²	200	8000	8350	2600 mm	-
50	1954	Pieter Postplein 18	block of flats	51m ²	377	6940	9185	2600 mm	-
51	1955	Wijnbesstraat 93	block of flats	83m ²	222	6045	9014	2600 mm	-
52	1959	Newtonstraat 83	block of flats	74m ²	241	6785	9640	2600 mm	-
53	1963	Einsteinstraat 113	block of flats	60m ²	60	6460	10210	2630 mm	-
54	1966	Motepad 31	block of flats	78m ²	96	7965	9000	2520 mm	-
55	1970	Meijhorst 3122	block of flats	66m ²	189	8780	10100	2600 mm	-
56	1973	Meijhorst 1488	block of flats	95m ²	270	10320	12000	2600 mm	-
57	1977	Zwaluwstraat 49	two-family	44m ²	215	5220	8120	2580 mm	-
58	1981	Rosa de Limastraat 14	block of flats	44m ²	86	5500	8500	2600 mm	-
59	1983	Minervaplaats 106	block of flats	32m ²	340	4870	6500	2500 mm	-
60	1987	Veemarkt 75	block of flats	73m ²	152	5770	11310	2450 mm	-
61	1992	Boeckstaetehof 607	block of flats	68m ²	144	6500	11500	2420 mm	-
62	1994	Blaise Pascalplein 38	block of flats	71m ²	119	7134	9770	2470 mm	-
63	1996	Rode Kruislaan 118	block of flats	104m ²	115	10530	10570	2470 mm	-
64	1998	Pater Leijdekkersstraat 34	block of flats	134m ²	54	7686	18810	2488 mm	-
65	2006	Deken Hensburchstraat 32	block of flats	80m ²	72	6650	12110	2600 mm	-
66	2008	Beatlesstraat 44	block of flats	115m ²	20	8300	15350	2610 mm	-
67	2009	Draaiom 98	block of flats	92m ²	115	7300	12300	2600 mm	-
68	2010	Henk van Tienhovenstraat 31	block of flats	77m ²	78	8400	9300	2620 mm	-

No.	year	bathroom	underground stor.	type of	private rooms	extra doors	first-floor	type of
		low. unit ; up. unit	low. unit ; up. unit	kitchen	low. unit; up. unit	low. unit; up. unit	spatial layout	exterior wall
1	1900	no	basement	separate	1	3	non-basic	massive
2	1902	no	basement	separate	3	0	basic (2 room)	massive
3	1911	no	b. closet	separate	disregarded	0	basic (2 room)	massive
4	1913	?	basement	?	?	?	?	massive
5	1913	no	basement	separate	0	1	basic (6 room)	massive
6	1922	no	b. closet	separate	3	0	basic (3 room)	cavity
7	1923	no	basement	separate	3	0	basic (2 room)	cavity
8	1923	no	basement	separate	3	0	basic (3 room)	cavity
9	1930	no	basement	separate	4	0	basic (3 room)	cavity
10	1938	no	basement	separate	3	0	basic (3 room)	cavity
11	1939	?	basement	?	?	?	?	cavity
12	1940	no	b. closet	separate	3	0	basic (3 room)	cavity
13	1948	yes	basement	separate	0	1	basic (4 room)	cavity
14	1949	yes	basement	separate	0	1	basic (4 room)	cavity
15	1950	yes	basement	separate	0	1	basic (4 room)	massive
16	1951	yes	no	separate	0	0	basic (4 room)	insul. cavity
17	1956	yes	b. closet	separate	0	1	basic (4 room)	cavity
18	1957	yes	basement	separate	0	2	basic (4 room)	cavity
19	1959	yes	basement	separate	0	0	basic (4 room)	cavity
20	1960	yes	basement	separate	0	2	basic (4 room)	cavity
21	1965	yes	b. closet	separate	0	0	?	cavity
22	1965	yes	b. closet	separate	0	0	basic (4 room)	cavity
23	1967	yes	no	separate	0	1	basic (4 room)	cavity
24	1973	yes	no	open	1	0	basic (5 room)	cavity
25	1977	yes	no	open	1	0	basic (4 room)	insul. cavity
26	1978	yes	no	open	0	0	basic (4 room)	insul. cavity
27	1981	yes	no	open	0	0	basic (4 room)	insul. cavity
28	1982	yes	no	open	0	0	basic (4 room)	insul. cavity
29	1990	yes	no	open	0	0	basic (5 room)	insul. cavity
30	1996	yes	no	open	0	0	basic (5 room)	insul. cavity
31	1997	yes	no	open	disregarded	0	basic (5 room)	insul. cavity
32	2000	yes	no	open	0	0	basic (5 room)	insul. cavity
33	2001	yes	no	open	0	0	basic (4 room)	insul. cavity
34	2005	yes	no	open	0	0	basic (4 room)	insul. cavity
35	2005	yes	no	separate	0	1	basic (5 room)	insul. cavity
36	2006	yes	no	open	0	0	basic (4 room)	insul. cavity
37	2008	yes	no	open	0	0	basic (5 room)	insul. cavity

No.	year	bathroom		underground stor.		type of kitchen	private rooms		extra doors		first-floor spatial layout	type of exterior wall
		low. unit	up. unit	low. unit	up. unit		low. unit	up. unit	low. unit	up. unit		
38	1901	yes	yes	basement	basement	separate	3	1	0	1	-	massive
39	1907	no	no	basement	basement	separate	2	0	1	1	non-basic	massive
40	1909	no	no	basement	basement	separate	2	0	1	1	basic (4 room)	massive
41	1912	no	no	basement	basement	separate	0	0	1	1	basic (5 room)	massive
42	1925	no	no	basement	no	separate	1	0	0	0	basic (2 room)	cavity
43	1927	no	no	basement	basement	separate	1	1	1	1	basic (3 room)	cavity
44	1934	no	no	basement	basement	separate	0	1	1	1	basic (3 room)	cavity
45	1934	no	no	b. closet	no	separate	0	0	1	1	basic (3 room)	cavity
46	1939	yes		basement		separate	3		2		-	cavity
47	1950	no	yes	basement	basement	separate	0	0	0	0	-	cavity
48	1951	no		basement		separate	0		1		-	cavity
49	1953	yes		basement		separate	2		1		-	cavity
50	1954	yes		basement		separate	1		0		-	cavity
51	1955	yes		no		separate	1		1		-	insul. cavity
52	1959	yes		no		separate	2		1		-	cavity
53	1963	yes		basement		separate	2		0		-	cavity
54	1966	yes		no		separate	2		2		-	cavity
55	1970	yes		no		separate	disregarded		1		-	cavity
56	1973	yes		no		separate	disregarded		0		-	cavity
57	1977	yes	yes	no	no	open	2	1	0	0	basic (4 room)	insul. cavity
58	1981	yes		no		open	0		0		-	insul. cavity
59	1983	yes		no		open	1		0		-	insul. cavity
60	1987	yes		basement		open	0		0		-	insul. cavity
61	1992	yes		no		open	2		2		-	insul. cavity
62	1994	yes		basement		open	2		2		-	insulated
63	1996	yes		basement		open	0		1		-	insul. cavity
64	1998	yes		basement		open	0		0		-	insul. cavity
65	2006	yes		no		open	3		2		-	insul. cavity
66	2008	yes		basement		open	0		0		-	insul. cavity
67	2009	yes		basement		open	1		0		-	insul. cavity
68	2010	yes		no		open	0		2		-	insul. cavity

No.	year	type of structure	first floor material/system	type of roof	material of roof struc.	insulation (mm)			type of sep. wall	sep. wall's thickness
						wall	roof	floor		
1	1900	beams + walls + multiple span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
2	1902	beams + walls + multiple span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
3	1911	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
4	1913	beams + walls + multiple span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
5	1913	beams + walls + multiple span	wood	flat	wood	0	0	0	massive	220 mm
6	1922	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	180 mm
7	1923	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
8	1923	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
9	1930	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
10	1938	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
11	1939	beams + walls + multiple span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
12	1940	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
13	1948	slabs + walls + multiple span	“perfora” system	side-gabled	wood	0	0	0	massive	220 mm
14	1949	slabs + walls + multiple span	“perfora” system	side-gabled	wood	0	0	0	massive	220 mm
15	1950	slabs + walls + multiple span	in-situ concrete	side-gabled	wood	0	0	0	massive	200 mm
16	1951	beams + posts + multiple span	steel	side-gabled	steel	25	8	0	massive	250 mm
17	1956	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
18	1957	slabs + walls + multiple span	“gemij” system	side-gabled	wood	0	0	0	massive	220 mm
19	1959	slabs + walls + multiple span	“isoliet” system	flat	wood	0	50	0	massive	210 mm
20	1960	slabs + walls + multiple span	“hollith” system	side-gabled	wood	0	0	0	massive	220 mm
21	1965	slabs + walls + multiple span	prefab con. slabs	side-gabled	wood	0	30	0	massive	220 mm
22	1965	slabs + walls + multiple span	in-situ concrete	flat	wood	0	0	0	massive	220 mm
23	1967	slabs + walls + multiple span	in-situ concrete	side-gabled	wood	0	0	0	decoup.	270 mm
24	1973	slabs + walls + single span	in-situ concrete	flat	wood	0	50	0	massive	240 mm
25	1977	slabs + walls + single span	in-situ concrete	side-gabled	wood	35	0	0	massive	180 mm
26	1978	slabs + walls + single span	wide slab floor	front-gabled	wood	40	40	0	massive	180 mm
27	1981	slabs + walls + multiple span	“dato” system	side-gabled	wood	40	40	0	decoup.	350 mm
28	1982	slabs + walls + single span	in-situ concrete	side-gabled	wood	40	40	0	massive	200 mm
29	1990	slabs + walls + single span	in-situ concrete	front-gabled	wood	70	75	100	massive	200 mm
30	1996	slabs + walls + single span	wide slab floor	single-sloped	wood	75	100	100	decoup.	300 mm
31	1997	slabs + walls + single span	wide slab floor	single-sloped	wood	100	100	120	massive	230 mm
32	2000	slabs + walls + single span	hollow chan. floor	hipped	wood	120	196	150	decoup.	220 mm
33	2001	slabs + walls + single span	hollow chan. floor	flat	concrete	120	120	150	decoup.	220 mm
34	2005	slabs + walls + single span	in-situ concrete	side-gabled	wood	125	195	200	massive	250 mm
35	2005	slabs + walls + single span	in-situ concrete	flat	concrete	90	100	205	massive	250 mm
36	2006	slabs + walls + single span	hollow chan. floor	flat	concrete	100	100	200	decoup.	300 mm
37	2008	slabs + walls + single span	hollow chan. floor	flat	concrete	100	100	120	decoup.	300 mm

No.	year	type of structure	first floor material/system	type of roof	material of roof struc.	insulation (mm)			type of sep. wall	sep. wall's thickness
						wall	roof	floor		
38	1901	beams + walls + multiple span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
39	1907	beams + walls + multiple span	wood	flat	wood	0	0	0	massive	220 mm
40	1909	beams + walls + multiple span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
41	1912	beams + walls + mixed span	wood	flat/single-slop.	wood	0	0	0	massive	220 mm
42	1925	slabs + walls + single span	st. beams/in-situ c.	side-gabled	wood	0	0	0	massive	220 mm
43	1927	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
44	1934	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
45	1934	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
46	1939	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
47	1950	slabs + walls + multiple span	in-situ concrete	side-gabled	wood	0	0	0	massive	200 mm
48	1951	slabs + walls + multiple span	“cusveller” system	side-gabled	wood	0	50	0	massive	220 mm
49	1953	slabs + walls + multiple span	“gemy” system	side-gabled	wood	0	0	0	massive	220 mm
50	1954	beams + walls + multiple span	wood	side-gabled	wood	0	0	0	massive	220 mm
51	1955	beams + posts + multiple span	steel	flat	steel	25	22	0	massive	250 mm
52	1959	slabs + walls + multiple span	“isoliet” system	flat	concrete	0	0	0	massive	210 mm
53	1963	slabs + walls + multiple span	in-situ concrete	flat	concrete	0	50	0	massive	220 mm
54	1966	slabs + walls + multiple span	“muwi” system	flat	concrete	0	0	0	massive	210 mm
55	1970	slabs + walls + multiple span	in-situ concrete	flat	concrete	0	70	0	massive	220 mm
56	1973	slabs + walls + multiple span	prefab con. slabs	flat	concrete	0	0	0	massive	180 mm
57	1977	slabs + walls + single span	wide slab floor	side-gabled	wood	30	40	0	massive	180 mm
58	1981	slabs + walls + single span	wide slab floor	single-sloped	wood	40	30	0	massive	200 mm
59	1983	slabs + walls + single span	wide slab floor	single-sloped	concrete	40	0	40	massive	230 mm
60	1987	slabs + walls + single span	wide slab floor	flat/single-slop.	concrete	40	40	50	massive	230 mm
61	1992	slabs + walls + single span	in-situ concrete	flat	concrete	70	110	40	massive	230 mm
62	1994	slabs + mix + multiple span	in-situ concrete	flat	concrete	90	60	0	massive	230 mm
63	1996	slabs + walls + multiple span	wide slab floor	flat	concrete	80	80	80	massive	250 mm
64	1998	slabs + walls + single span	wide slab floor	flat	concrete	80	80	75	massive	300 mm
65	2006	slabs + walls + single span	wide slab floor	side-gabled	wood	140	100	50	massive	180 mm
66	2008	slabs + mix + multiple span	wide slab floor	flat	concrete	170	120	160	massive	200 mm
67	2009	slabs + walls + single span	wide slab floor	flat	concrete	120	100	100	massive	300 mm
68	2010	slabs + walls + multiple span	wide slab floor	single-sloped	concrete	100	90	170	massive	300 mm

Appendix 2.

Design tactics' mentions.

source	page	mentions of a design tactic	overdesigned	blank	uniform	diverse	appropriate	undemanding	convenient	robust	unique	intelligible
Altan et al., 2015	5493	...the <u>off-center position</u> [of the main entry] permits the creation of two spaces, <u>for big and small windows</u> , a solution that allows a division of the interior space in the future.				x						
Altan et al., 2015	5493	...the bathroom found the right arrangements at the opposite side of the central area. In this particular situation, an inflexible space such as the bathroom, helped to create a distinct division of the apartment into three different areas, and at the same time, the possibility of considering all the remaining spaces as unique zones (Figure 4b).	?	?	?	?	?	?	?	?	?	?
Altan et al., 2015	5493	The positioning of the <u>staircase and washroom</u> ... These are, in effect, two <u>inflexible elements</u> that once placed cannot be easily moved...	x									
Altan et al., 2015	5493	The washroom in the back might have an external window that would also <u>allow natural ventilation</u> ...				x						
Altan et al., 2015	5493	...the stairs in that position creates an independent nucleus and a new <u>entry</u> to the building, and to <u>each independent level</u> of the building.		x								
Altan et al., 2015	5494	Tenants can convert different zones using sliding walls, i.e., <u>sliding walls</u> for <u>daily changes</u> or through more or less flexible walls (Figure 5b).					x					
Altan et al., 2015	5495	The internal space resulting from the division is a <u>long</u> and dynamic space of 48 m2 that can meet the needs of different tenants.	x									
Arge, 2005	121	The most important measures giving high generality in office buildings are: <u>building width</u> – <u>allowing</u> for different work place designs or solutions;	x									
Arge, 2005	121	... <u>floor to floor height</u> net – <u>allowing</u> for different work place designs or solutions, for example, work stations across the whole floor;	x									
Arge, 2005	121	... <u>technical grid</u> – allowing for different work place designs or solutions.		x								
Arge, 2005	121	In addition, <u>raised floor</u> ... contribute to high generality in office buildings.						x				
Arge, 2005	121	In addition, ... <u>zone based</u> electrical and ICT <u>service</u> ... contribute to high generality in office buildings.		x								
Arge, 2005	122	The most important measures giving high flexibility in office buildings are: <u>modularity</u> – the most commonly used flexibility measure...					x					
Arge, 2005	122	... <u>plug and play building elements</u> – allowing for fast changes of layouts or technical services parts;						x				
Arge, 2005	122	... <u>flat</u> ... suspended <u>ceiling</u> – contributing to rapid and easy moving of internal walls.	x									
Arge, 2005	122	... <u>soundproof</u> suspended <u>ceiling</u> – contributing to rapid and easy moving of internal walls.	x									
Arge, 2005	122	...building form or organization of space – allowing for parts of the building to be used by different organisations or user groups;	?	?	?	?	?	?	?	?	?	?
Arge, 2005	122	...functional organisation – <u>separating</u> functions with <u>different functional performance</u> , allowing for the building to be used by different organisations or user groups;			x							

source	page	mentions of a design tactic	overdesigned	blank	uniform	diverse	appropriate	undemanding	convenient	robust	unique	intelligible
Arge, 2005	122	The most important measures giving high elasticity in office buildings are:... <u>fire sprinkling</u> – allowing for <u>continuous space units</u> ;	x									
Arge, 2005	122	...EIB/LonWorks – easing changes in the configuration of spaces to be rented or sold.	?	?	?	?	?	?	?	?	?	?
Beisi and Yingying, 2011	20	The building's walls, <u>unfettered by weight</u> , could be <u>extremely thin</u> ; they could even be replaced by doors, windows, or pieces of furniture.						x				
Beisi and Yingying, 2011	22	Another equally important factor is the <u>separation</u> of the <u>structure</u> from the <u>enclosure</u> . As a result, immense flexibility is created...					x					
Beisi and Yingying, 2011	22	...the key to changing an element in an ancient building... is to support the weight from the upside temporarily (Du, 1993)... [due to] the <u>systematic assembly</u> of the elements of the structure.					x					
Beisi and Yingying, 2011	22	Large woodwork... is composed of beams, columns, bracket sets, and roofs that are connected <u>without the use of nails</u> (Figure 2)... All parts of large woodwork can be changed independently.						x				
Beisi and Yingying, 2011	23, 24	...spatial extension of the house is controlled by certain patterns that are planned and designed at the start of construction... In short, interactive influence between the house and the particular culture determines the development pattern of a house.	?	?	?	?	?	?	?	?	?	?
Beisi and Yingying, 2011	24	This represents another characteristic of Chinese traditional buildings: <u>neutrality of space</u> ... [example] The name of the left-wing of the back hall depended on the activity held in it...		x								
Beisi and Yingying, 2011	25	<u>Differences</u> in function as bedroom, living room, and hall were <u>only</u> evident <u>in</u> the types of <u>furniture</u> placed within the rooms while a similar <u>spatial dimension</u> was <u>shared</u> (Jia & Wang, 1998:3-4).		x								
Beisi and Yingying, 2011	27	<u>Standardization</u> ... existed among parts of a single building... As all part sizes were confirmed by a <u>certain modulus unit</u> ... all parts could be manufactured offsite.		x								
Beisi and Yingying, 2011	28	The <u>separation</u> of two levels, <u>large</u> woodwork, and <u>small woodwork</u> allows Chinese traditional buildings to be changeable and flexible.					x					
Beisi and Yingying, 2011	29	A... building with <u>fixed components</u> will only shorten its life span because of functional deterioration. An alternative solution is to <u>divide</u> the structure into <u>different levels</u> ...					x					
Beisi and Yingying, 2011	28-29	... <u>standardization</u> , which provided great possibilities in the <u>development of infill</u> components.									x	
Beisi and Yingying, 2011	30	...these [standardization and industrialization] may be considered as... <u>a way to pay greater attention to the specific</u> design of certain components.										x
Belausteguigoi-tia et al., 2011	95	...it is the <u>great structures</u> ... what enables a physical polyvalence to host a variety of uses.	x									
Belausteguigoi-tia et al., 2011	95	...it is the... <u>absence of partitions</u> what enables a physical polyvalence to host a variety of uses.	x									
Belausteguigoi-tia et al., 2011	96	...are built with <u>post and beam</u> concrete structures... and could therefore allow for change in the floor plan layout.	x									

source	page	mentions of a design tactic	overdesigned	blank	uniform	diverse	appropriate	undemanding	convenient	robust	unique	intelligible
Belausteguigoi-tia et al., 2011	96	...the extended <u>use of brick</u> for interior partitions makes adaptation a complex process that <u>involves time</u> and user <u>discomfort</u> ... The recent use of <u>lighter solutions</u> ... contributes to adaptability.						X				
Belausteguigoi-tia et al., 2011	98	...those with <u>less structural elements</u> in plan provide the maximum adaptability to different user-activities... a <u>clear plan</u> with <u>few</u> master <u>partitions</u> enables versatility for a variety of uses...	X									
Belausteguigoi-tia et al., 2011	98	...off-site industrialized systems... allows buildings to grow or reduce in size according to their needs, with <u>little impact</u> for their inhabitants.						X				
Belausteguigoi-tia et al., 2011	98	These [open building] systems are... able to be collocated in different types of buildings... and in different contexts; usually make use of pretentiously <u>universal joints</u> , <u>delimited modular ranges</u> ...		X								
Belausteguigoi-tia et al., 2011	99	The choice of modules only consisting of the <u>minimum number of pillars</u> is the cornerstone to provide an adaptable space.	X									
Belausteguigoi-tia et al., 2011	101	... <u>bathrooms</u> ... poses a certain <u>design limitation</u> , as, once built, these elements prevail throughout the different plan distributions.	X									
Belausteguigoi-tia et al., 2011	101	Interior partitions are made up of industrialized plaster boards that offer a <u>simple assembly</u> and are able to be taken entirely apart...									X	
Belausteguigoi-tia et al., 2011	101	...although <u>partitions</u> do have to <u>follow the modules</u> to a certain degree. This can be considered a <u>design limitation</u> .	X									
Brand, 1994	13	Many buildings are demolished early if their outdated systems are too <u>deeply embedded</u> to replace easily.					X					
Brand, 1994	18	...[it] is kept adaptable... by its modest lot size... [when] property remains in many hands... many people make <u>many different decisions</u> , thereby ensuring <u>variety</u> in the resulting environment.			X							
Brand, 1994	20	An adaptive building has to <u>allow slippage</u> between the differently-paced systems... Otherwise the slow systems block the flow of the quick ones, and the quick ones tear up the slow ones...					X					
Brand, 1994	20	Timber-frame buildings... conveniently <u>separate</u> Structure, Skin, and Services, while balloon-frame... <u>over-connects</u> them.					X					
Brand, 1994	23	Or the building may be blessed with <u>durable</u> construction and <u>resilient</u> design which can forgive insult and hard swerves of usage.							X			
Brand, 1994	24	They can't wait to... put it [the space] immediately to work. What these buildings have in common is that they are... <u>spacious</u> .	X									
Brand, 1994	24	...its 3000-square-foot space <u>column-free</u> ... [others] found the space easily converted to their special needs.		X								
Brand, 1994	24	The building was <u>too humble</u> for anyone to worry about whether they were violating its historical or aesthetic integrity.		X								
Brand, 1994	60	Redefining space inside [domes] was <u>difficult</u> , adding anything to the outside nearly <u>impossible</u> – a <u>cut-and-try</u> process...					X					
Brand, 1994	60	Worst of all, domes couldn't grow or adapt... a <u>cut-and-try process</u> of <u>matching</u> compound angles and curves.				X						
Brand, 1994	60	[octagon-shaped] Like domes, they proved <u>awkward</u> to subdivide or add to...				X						

source	page	mentions of a design tactic	overdesigned	blank	uniform	diverse	appropriate	undemanding	convenient	robust	unique	intelligible
Brand, 1994	60-61	Right-angled shapes <u>nest and tile with each other universally</u> The “specious old box” is <u>old</u> because it is profoundly adaptive.			x							
Brand, 1994	74	The codes... requiring <u>heavy-duty</u> wiring in case more electricity is needed later, <u>strong</u> walls in case extra stories are added later...	x									
Brand, 1994	75	Small lots give greater individual control and thus greater <u>variety</u> ... The more owners, the more gradual and adaptive the ongoing change.				x						
Brand, 1994	80	...do you want the prospective buyer to see... [a neighbouring house with] a metal roof <u>instead of</u> tile, or a <u>nonstandard</u> dormer sticking out? Well, <u>if they can't, you can't</u> . This... prevents buildings from... getting better with time.				x						
Brand, 1994	89	<u>Large</u> houses are exceptionally skilled at being comfortable, being loved, and being adaptable...	x									
Brand, 1994	89	Large <u>houses</u> are exceptionally skilled at <u>being comfortable</u> , being loved, and being adaptable...					x					
Brand, 1994	104	The best buildings are... those that are strong enough to retain their <u>character</u> as they accommodate different functions over time.”									x	
Brand, 1994	108	Some kinds of buildings are impossible... to find new uses for, usually because they are <u>too specialized</u> or <u>too large</u> ... [e.g.] Theatres have a huge, <u>oddly segmented</u> space with few horizontal surfaces...					x					
Brand, 1994	108	Houses are the one species of building most thoroughly <u>coevolved with human use</u> , and that congeniality carries over...					x					
Brand, 1994	108-109	Warehouses and factories... built between 1860 and 1930 are endlessly adaptable. They are <u>broad</u> ... and <u>high ceilings</u> of 12 to 18 feet. The floors, <u>built strong</u> enough for storage... can handle any new use...	x									
Brand, 1994	108-109	Warehouses and factories... built between 1860 and 1930 are endlessly adaptable. They are... <u>clear-spanned</u> or <u>widely columned</u> ...	x									
Brand, 1994	108-109	Warehouses and factories... built between 1860 and 1930 are endlessly adaptable. They are... with <u>good natural illumination and ventilation</u> ... Architectural <u>ornament</u> ... is... <u>modest</u> and therefore appreciated.					x					
Brand, 1994	109	Another trait that invites longevity is <u>strangeness</u> . Almost any sufficiently <u>odd building</u> that has a modicum of functionality... will attract supportive community bemusement...									x	
Brand, 1994	113	...buildings look and feel increasingly like movie sets: impressive to the eye, <u>flimsy</u> to the touch, and incapable of aging well.								x		
Brand, 1994	115	The <u>simpler</u> the roof, the better. Chimneys... and other complications all invite problems with flashing, and the make reroofing difficult.										x
Brand, 1994	120	Who builds in wood builds a shack... The exception is timber-framed buildings... it is <u>massive</u> ...								x		
Brand, 1994	120	...adaptable now, gone soon. The exception is timber-framed buildings... it is <u>exposed</u> . Air and eyeballs can get at it to keep it dry and <u>inspected</u> .										x
Brand, 1994	125	Concrete is <u>so solid</u> and so laced with steel reinforcing <u>that cutting</u> a new door or window is virtually <u>unthinkable</u> .						x				

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Brand, 1994	126	Wood and brick walls invite change by <u>involving us</u> in their upkeep. What begins as repair easily becomes improvement...										X
Brand, 1994	127	...the building wears down so fast... <u>solidifying</u> stud construction a bit more may get a better result.								X		
Brand, 1994	129	...whose systems and materials are <u>intuitively obvious</u> ...As they become more <u>complicated</u> ... [they] require the attention of <u>specialists</u> to inspect and maintain...										X
Brand, 1994	129	Too much is <u>invisible</u> – the pressure regulator in the gas meter, the rot in the walls, the location of the short circuit...										X
Brand, 1994	134	...columns <u>articulate</u> space in a way that makes people feel comfortable making and remaking... You can always <u>visualize</u> what you might do... huge free-span interior spaces is... a loss for <u>intuitive adaptability</u> .										X
Brand, 1994	134	The <u>identical</u> bays... and the additive <u>identical</u> rooms... had been found to be the most inexpensively adaptable over time...		X								
Brand, 1994	139	Medium to large houses survived the best, because there is <u>always use for them</u> ... <u>Everybody can find a use</u> for a 12- or 14foot-square building.				X						
Brand, 1994	139	Medium to large houses survived the best... Small houses were built <u>shoddy</u> and <u>disposable</u> ...								X		
Brand, 1994	139	Barns survived fairly well, thanks to being <u>solidly</u> constructed...								X		
Brand, 1994	150	<u>Specialized knowledge</u> distances buildings from users.										X
Brand, 1994	150	<u>Specialized space</u> hinders future flexibility.				X						
Brand, 1994	150	... <u>devoid of interruption</u> or ornament... made it... easy to add to.		X								
Brand, 1994	150	The roof's <u>simplicity</u> made it leak-free, cheap to build and maintain, and easy to add to.										X
Brand, 1994	151	What are the traits, then, that selection preferred... It looks respectable but stands apart from fashion, secure in the <u>conservatism</u> ...				X						
Brand, 1994	155	So long as people of modest means <u>outnumber</u> the rich, small will always win.				X						
Brand, 1994	162-163	...the <u>easiest</u> , cheapest and <u>quietest</u> direction [to expand]... is into existing "raw" space whose initial function is deemed dispensable...							X			
Brand, 1994	162-163	Houses evidently <u>need more</u> low-definition space for later expansion...	X									
Brand, 1994	163	Another frequent error is installing built-in furniture... Soon enough you have to <u>demolish the walls to move the furniture</u> .					X					
Brand, 1994	169	... <u>standing on an old chair</u> , <u>sweating</u> and <u>cursing</u> the moment... of stringing 100 feet of... telephone wire... through the dropped ceiling...							X			
Brand, 1994	170	Their <u>floor-to-ceiling height</u> was <u>too low</u> . There was no room for both a dropped ceiling and a raised floor, and no way to fix the problem.	X									
Brand, 1994	171	When the <u>trends</u> moved on, the buildings were left standing... Their failure is the failure of <u>optimization</u> as a design strategy.				X						

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Brand, 1994	174	Their high ceilings, <u>daylit shallow depth</u> , and <u>openable windows</u> turned from embarrassments back into virtues without benefit of intent.					x					
Brand, 1994	174-175	... <u>humane design</u> ... <u>Modest depth</u> , <u>high ceilings</u> , <u>operable windows</u> ,... and <u>individually controllable amenities</u> such as window awnings.					x					
Brand, 1994	174-175	...any new office building he designs be potentially convertible into housing... [due to] <u>massive construction</u> ...	x									
Brand, 1994	174-175	...any new office building he designs be potentially convertible into housing... [due to] <u>raised floor rather than dropped ceiling</u> for services...						x				
Brand, 1994	176	So MIT's Main Building... [a] <u>narrow</u> 64 feet wide – just right...					x					
Brand, 1994	176	...64 feet wide – just right for a <u>wide corridor</u> in the middle, <u>with space for</u> a variety of [spaces]... (A later MIT building of 55-foot width was found to be inflexibly restrictive.)	x									
Brand, 1994	179	... [It] is burdened with... expensive <u>overspecified spaces</u> , such as... rooms designed for... research that was no longer even going on...					x					
Brand, 1994	186	... <u>overbuild</u> Structure... provide <u>excess</u> Services capacity; go for <u>oversize</u> ("loose fit") rather than differently.	x									
Brand, 1994	186	"Use materials from <u>near at hand</u> ,"... "They'll be easier to match or replace."						x				
Brand, 1994	186	A spatially <u>diverse</u> building is easier to make use adjustments in than a spatially <u>monotonous</u> one – people can just move around.				x						
Brand, 1994	187	The most convenient form of expansion is <u>cellular</u> ... made up of a <u>series of</u> bays... If the company expands... take over its [a neighbour's] space... In hard times, shrink back...			x							
Brand, 1994	191	COLUMNS... make it <u>easy to imagine</u> changes, easy to put them in, easy to remove them.										x
Brand, 1994	192	...start boxy and <u>simple</u> ... Prematurely <u>convoluted</u> surfaces are expensive to build, a nuisance to maintain, and hard to change.										x
Brand, 1994	192-193	The <u>generous width</u> [six feet on average] of the hall is also the major reason for the inherent flexibility of the box. ³	x									
Brand, 1994	193	<u>Each is</u> lit and ventilated... <u>each has</u> access to the corridor, <u>each is</u> capable of opening into adjoining rooms... simple, <u>autonomous</u> rooms can be constantly readapted without stress to the building.			x							
Brand, 1994	194-195	Wood is already the most adaptive of all building materials because <u>amateurs are comfortable messing with it</u> ...										x
Brand, 1994	194-195	Timber frame was the original design-for-disassembly building material – <u>just knock out the pegs</u> ...						x				
Brand, 1994	195	Roofs that are built <u>fussy</u> at the beginning are an obstacle to later change.	x									
Brand, 1994	195	Galvanized steel studs are cheaper, <u>lighter</u> ... <u>easier</u> to cut (metal snips), and <u>conveniently</u> holed for stringing conduit and pipe...						x				
Brand, 1994	195	They [galvanized steel studs] take <u>less skill</u> to work with than wood...										x

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Brand, 1994	195	Galvanized steel studs are... <u>straighter</u> (no warp)...			x							
Brand, 1994	196	...keeping Services <u>separate</u> from Skin as well as from Structure... hiding wires and pipes in walls makes maintenance and improvement a major hassle...						x				
Brand, 1994	196	...installing <u>over-capacity</u> electrical feeders and breakers, <u>oversize</u> chases, and an apparent <u>excess</u> of outlets is nearly always rewarded.	x									
Brand, 1994	196	The general rule is: <u>oversize</u> your components... All new buildings should have <u>extra</u> conduit laid throughout...	x									
Brand, 1994	203	Buildings that last are made of <u>quality</u> materials and with <u>quality</u> craftsmanship... [it pays] in terms of durability and flexibility.								x		
Brand, 1994	206	...part... lovingly and carefully ... and... parts... very roughly... the compensation between the two is <u>necessary</u> in a real thing." Undifferentiated, unpartitioned, unspecialized... spaces are <u>essential</u> .				x						
Brand, 1994	208	...people's dislike of grossly pure shapes... "simple shapes are <u>inhuman</u> . They fail to <u>resonate</u> with the way nature organizes itself...				x						
Bruce et al., 2015	151	...some structures... can... provoke a demand for retrofitting purely through their <u>architectural</u> and historical <u>merit</u> ...									x	
Bruce et al., 2015	151	...[some] buildings... cannot be <u>easily demolished</u> due to their proximity to... [others] as well as sharing common footings with... [others]						x				
Bruce et al., 2015	160	...the <u>quality</u> of the building's internal structure and the <u>durability</u> of the materials that it was initially constructed from are very important...								x		
Bruce et al., 2015	160	...the <u>layout of the structural system</u> ... are all factors that can seriously <u>restrict</u> the end use of the building.		x								
Bruce et al., 2015	160	...the... <u>floor to ceiling heights</u> ... are all factors that can seriously <u>restrict</u> the end use of the building.		x								
Bruce et al., 2015	160	...windows could present a barrier to retrofitting of multi-storey building and the <u>ease of replacement</u> would be an important factor.					x					
Bruce et al., 2015	160	...tenants and investors are now looking for <u>large... spaces</u> and do not want columns and walls restricting their floor plans.	x									
Bruce et al., 2015	160	...tenants and investors are now looking for... <u>open spaces</u> and do not want columns and walls restricting their floor plans.		x								
Bullen and Love, 2011a	34	When considering a building for adaptive reuse it is essential to examine the... <u>condition</u> of... systems...								x		
Bullen and Love, 2011a	34	When considering a building for adaptive reuse it is essential to examine the... their [systems'] <u>capacity</u> for modification;	x									
Bullen and Love, 2011a	34	When considering a building for adaptive reuse... examine the... building's <u>structural layout</u> and its capacity to accommodate required spaces and functions;		x								
Bullen and Love, 2011a	39	Buildings such as a prison would not present many opportunities for reuse due to <u>extensive compartmentalization</u> .	x									
Bullen and Love, 2011a	39	... <u>low-rise</u> buildings... did not... utilize the available plot ratio or zoning... a <u>greater financial return</u> may be obtained from... <u>high-rise</u> ...				x						

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Bullen and Love, 2011a	39	<u>Small</u> cottages in a terrace would be extremely hard to adapt due to <u>limitations</u> of space.	X									
Bullen and Love, 2011a	39	Large steel sheds... while <u>spacious</u> may generate little value for retention...	X									
Bullen and Love, 2011a	39	Large steel sheds... may generate little value for retention as they are <u>too specialized</u> .					X					
Bullen and Love, 2011a	39	Unless a built asset has some <u>redeeming esthetic features</u> ... its reuse may not be an... option.									X	
Bullen and Love, 2011a	40	Conversion... to a functional new building was ultimately influenced by its <u>structural integrity</u> ...								X		
Bullen and Love, 2011a	40	Conversion... to a functional new building was ultimately influenced by its... <u>spatial layout</u> ...		X								
Bullen and Love, 2011a	40	Other issues.. how <u>technically difficult</u> it would be to convert and install new services that would be required...					X					
Bullen and Love, 2011a	40	...have low suitability for reuse as they were... <u>poorly constructed</u> ...								X		
Bullen and Love, 2011a	40	...have low suitability for reuse as they... used <u>thermally inefficient</u> materials and techniques.	X									
Bullen and Love, 2011a	41	... <u>layout</u> ... of the existing building rendered it economically unviable to adapt to the current building code.		X								
Bullen and Love, 2011a	41	... <u>spatial attributes</u> of the existing building rendered it economically unviable to adapt to the current building code.	X									
Bullen and Love, 2011b	413	...or their <u>layout</u> may be <u>inappropriate</u> for any change of function...		X								
Bullen and Love, 2011c	39	The current <u>layout</u> ... may also be <u>inappropriate</u> for any change of use, particularly if it contains a <u>large number of columns</u> ...		X								
Bullen and Love, 2011c	39	...older buildings typically do not provide voids or <u>access ways</u> ... to retrofit modern services such as air-conditioning.						X				
Bullen and Love, 2011c	39	...older buildings typically do not provide... <u>sufficient room</u> to retrofit modern services such as air-conditioning.							X			
Conejos et al., 2016	509	(2) Physical restrictions: Restrictions due to existing <u>floor layouts</u> , <u>number of columns/walls</u> and <u>structural system layouts</u> ...	X									
Conejos et al., 2016	512	A new <u>lightweight</u> structure of steel and glass that <u>clipped</u> inside the church was also provided to ensure reversibility in the future.						X				
de Neufville, 2008	53	...easily adjust to short- and long-term shifts of traffic through the building. In the short run, operators <u>open and close doors</u> between various sectors. In the long run, they can <u>displace panels</u> .					X					
de Neufville, 2008	57	Flexible designs... simultaneously <u>create both traditional</u> and <u>low-cost</u> facilities at a new airport, to appeal to the <u>range of</u> possible customers.			X							
de Neufville, 2008	62	...a <u>half-sized</u> standard building <u>supplemented by</u> low-cost facilities and featuring bus services to remotely parked aircraft... suitable... for easy expansion emphasizing either traditional or low-cost carriers...			X							

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Dhar et al., 2013	143	...structural systems... which are <u>mostly load-bearing</u> brick <u>walls</u> ... significantly hinder flexibility, and reduce scopes of future changes...	X									
Dhar et al., 2013	144	...the <u>support places limitation on</u> the <u>layout</u> possibilities due to the positions and dimensions of walls, floors, columns, ducts...	X									
Dhar et al., 2013	150	... <u>irregular</u> ... column <u>spans</u> may limit the number of possible layouts...		X								
Dhar et al., 2013	150	... <u>smaller</u> column <u>spans</u> may limit the number of possible layouts...	X									
Dhar et al., 2013	150	A layout having a staircase <u>at the middle</u> , or around middle position of a building, can allow for more flexibility than placing it <u>at the corner</u> .		X								
Dhar et al., 2013	150	... <u>roof beams</u> ... often <u>guide to configure</u> the livable space and have impact on it...	X									
Dhar et al., 2013	150-151	[By] ...installing these wiring systems between partitioning walls... A <u>re-installation</u> of wiring systems is required <u>in every renovation</u> work					X					
Dhar et al., 2013	150-151	Vertical service distribution ducts... are very difficult to adapt for a new layout. The position of <u>ducts</u> often <u>limits</u> the options of future changes.	X									
Dhar et al., 2013	152	... <u>column/load-bearing wall-free space</u> may be able to be used for any purpose and be ready to go for any future changes.	X									
Dhar et al., 2013	152	...major wiring work in... adaptable walls... involves <u>technical challenges</u> for moving or altering into a new layout...					X					
Dhar et al., 2013	154	Moderate flexibility... <u>frame structure</u> ... Minimum flexibility... <u>load-bearing brick-wall structure</u> ...	X									
Dhar et al., 2013	154	Moderate flexibility... <u>Flat plate</u> structural system...	X									
Dovey and Fisher, 2014	54	...these are learning <u>clusters</u> where... <u>two or more</u> traditional classrooms... [can] be converted into a single commons.		X								
Dovey and Fisher, 2014	54	...these are learning clusters where <u>flexible walls</u> enable... classrooms... to be converted...					X					
Dovey and Fisher, 2014	58	...fluidity is an adaptive condition produced by a <u>conjunction of</u> openness and closure rather than <u>one or other end</u> of this continuum.		X								
Dovey and Fisher, 2014	58	...high level of reversibility through the use of <u>removable</u> (folding, sliding) <u>walls</u> ...					X					
Dovey and Fisher, 2014	58	...since the <u>closed</u> classroom constrains new pedagogies and the <u>open</u> plan constrains traditional teaching.		X								
Dovey and Fisher, 2014	60	The most resilient of the plans are those with a <u>diversity</u> of learning spaces and high levels of fluidity.		X								
Eguchi et al., 2011	74	The house contains <u>no load bearing walls</u> and uses... columns...	X									
Eguchi et al., 2011	74	The house... uses a system of <u>thin</u> columns... that can be removed or extended...						X				
Eguchi et al., 2011	74	...the entire house is based on a <u>single</u> philosophy of <u>measurement</u> ... making it easy to change and extend.		X								
Eguchi et al., 2011	74-75	...with <u>light</u> double sliding windows and partitions (fusuma) allowing them to be shifted or stored easily.						X				

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Eguchi et al., 2011	75	...rooms bore <u>no functional labels</u> , rather as multi-functional spaces... deriving <u>its identity</u> from its temporary occupants...		X								
Eguchi et al., 2011	75	This system <u>divides</u> the building parts... so that parts with long life spans are not damaged when parts with short life spans are replaced...					X					
Eguchi et al., 2011	77	A key tactic was shifting to a 10.8m uniform-grid offering a <u>low cost solution</u> , which is <u>typically</u> used for shopping centres and parking – in contrast to the typical office span of 16-18m...				X						
Eguchi et al., 2011	77	... <u>external</u> lateral bracing... creates a rigid shell and allows for a <u>free internal space</u> that was envisioned to incorporate future changes...	X									
Eguchi et al., 2011	77	...by positioning... <u>static core spaces</u> along the periphery and <u>opening</u> the center <u>up</u> ... allowing the design to accommodate ongoing changes...	X									
Eguchi et al., 2011	77-78	The convertibility... is augmented by the <u>decentralization</u> of... services into 10 modules along the east and west periphery.		X								
Eguchi et al., 2011	78	...they are <u>removable</u> , being fastened through <u>dry</u> connections.						X				
Eguchi et al., 2011	79	...MK utilizes a 'universal space' which they signify through a <u>column-free</u> work space.	X									
Eguchi et al., 2011	79	Wooden components... all of which are made with <u>standard sizes</u> - providing <u>easy availability</u> in the future...				X						
Eguchi et al., 2011	79	...wooden parts... are assembled with <u>dry joints</u> (screws) increasing their refitability in the future.						X				
Eguchi et al., 2011	79	...the building also <u>decentralizes</u> services to the outside which help allow for <u>distributed control</u> of the services amongst different tenants.		X								
Eguchi et al., 2011	80-81	...drive market value by emphasizing the <u>uniqueness</u> offered by the original characteristics...									X	
Eguchi et al., 2011	82	...where the structural floor height is <u>not large enough</u> due to the demand for raised flooring to equip the latest service devices...	X									
Eguchi et al., 2011	82	"If the building has a good enough <u>structural frame</u> , including <u>large open spaces</u> , there are no obstacles to realize adaptability".	X									
Eguchi et al., 2011	82	...to be able to <u>subdivide</u> services to a <u>minimum floor area</u> due to greater demand to partition larger spaces... for more <u>individual control</u> .		X								
Eguchi et al., 2011	83	...to maximize profitable space allowances, lock buildings into <u>specific uses</u> , making change of use difficult...				X						
Engel and Browning, 2008	127	...certain parts of a system should be designed so as to be <u>easily decoupled</u> from the rest of the system to facilitate partial upgrades.				X						
Engel and Browning, 2008	130-131	...modular design of a complex system <u>facilitates adaptations</u> to future uncertainty by <u>decreasing the cost</u> of the option to modify the system.				X						
Engel and Browning, 2008	130-131	From an engineering perspective, modularization has three main purposes: 1. To make a system's <u>complexity</u> manageable,...									X	
Engel and Browning, 2008	136	...there is more overall architectural option value in <u>many small</u> design clusters than in a <u>few large</u> ones.		X								

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Engel and Browning, 2008	136	...the overall <u>cost of interfaces</u> increases linearly with <u>their number</u> and individual attributes.					X					
Engel and Browning, 2008	143	...the likely ease with which its modules can be changed <u>without disrupting</u> other modules.					X					
Engel and Reich, 2015	396-397	...increasing system's modularity... may decrease the lifetime value of a system due to <u>excessive costs</u> related to the system's interfaces.				X						
Engel and Reich, 2015	397	...systems... composed of <u>separate</u> functional modules... could be adapted to new requirements with relative ease and at a low cost...					X					
Engel and Reich, 2015	397	...systems... interacting via <u>standard</u> interfaces, could be adapted to new requirements with relative ease and at a low cost...		X								
Engel and Reich, 2015	399	...an optimal system design between a <u>monolithic</u> , nonadaptive, but less expensive system...					X					
Engel and Reich, 2015	399	...a fully adaptive but <u>expensive</u> [system]...The tradeoff is found by combining some components... and thus saving their intramodule ICs.				X						
Engel and Reich, 2015	400	...the tradeoff between the benefits of <u>having many small options</u> ... and the <u>costs of the interfaces</u> to maintain them.					X					
Engel and Reich, 2015	411	...an adaptable system is... to base the design on a <u>large number of small modules</u> ... such architecture requires <u>dealing with more interfaces</u> ...					X					
Fawcett et al., 2012	549	...to expand/upgrade: this often involves the provision of redundancy or <u>overcapacity</u> in the initial design/construction...	X									
Fawcett et al., 2012	549	...installing a highcost <u>dual-fuel</u> boiler because it creates the option to <u>switch</u> fuels in response to future changes...			X							
Fernandez, 2003	171	Flexible and adaptable buildings... Included here are <u>moveable</u> workplace partition systems... <u>knock-out</u> panels for expansion...						X				
Fernandez, 2003	172	...aspired to significant capabilities to alter its internal spaces through <u>movable</u> floors and partitions...					X					
Fernandez, 2003	172-173	The design did not use any <u>welded</u> connections, <u>laminated</u> glass... that would make difficult material reclamation and recycling.						X				
Fernandez, 2003	174	...a <u>diversified</u> lifetimes (DL) strategy is that a project... may reduce the risk of misutilization by distributing <u>a range of</u> building lifetimes throughout the physical systems of the architecture...			X							
Fernandez, 2003	181	A tectonic that is based on change is a very different assembly than that based on the idea of a <u>monolithic</u> , unchanging building.					X					
Fletcher et al., 2009	280	...disassembly... was quite difficult. <u>Three tools</u> were needed...						X				
Fletcher et al., 2009	280	The internal components... are <u>permanently affixed</u> to the motherboard... making user changes... difficult if not impossible.						X				
Fletcher et al., 2009	280	The computer is easily disassembled with only <u>one tool</u> necessary to remove all of the components (a generic Phillips head screwdriver)...						X				
Fletcher et al., 2009	282	...with increasing <u>numbers of interconnections</u> , it becomes more and more difficult to perform an adaptation task in the future...					X					

source	page	mentions of a design tactic	overdesigned	blank	uniform	diverse	appropriate	undemanding	convenient	robust	unique	intelligible
Fletcher et al., 2009	282	...for maximum adaptability... a perfect hierarchical structure (no cross-connections) is referred to as a segregated product architecture.						X				
Fletcher et al., 2009	286	Adaptability is defined here as a function of the product architecture ...						X				
Fletcher et al., 2009	286	Adaptability is defined here as a function of... the relative size of the various system components .						X				
Fletcher et al., 2009	287	...the model is capable of various configurations through the use of repeated components ... common interfaces ...		X								
Fletcher et al., 2009	287	...the model is capable of various configurations through the use of... functional independence ...						X				
Georgiadou et al., 2012	148	...“a good low-energy design offers the best future-proof solutions”, as buildings of the future must be energy efficient .	X									
Georgiadou et al., 2012	152	Flexibility in the building envelope; i.e., space for energy storage systems, PV-ready roofs.	X									
Georgiadou et al., 2012	152	Designing to higher standards to remain compliant with imminent policy, such as the zero carbon homes requirement...	X									
Gijsbers and Lichtenberg, 2014	240	...a layering system ... where the building parts that will be adapted most frequently can be reached with minor interference to other layers...						X				
Gijsbers and Lichtenberg, 2014	240	Essential features to realize adaptations are among others: demountability , accessibility of connections, modulation and reusability...						X				
Gijsbers and Lichtenberg, 2014	247, 250	These wall elements consist of... storey high ... panels... The advantage... is the construction speed ...						X				
Gijsbers and Lichtenberg, 2014	247, 250	These wall elements consist of... lightweight panels... The advantage... is the construction speed...						X				
Gijsbers and Lichtenberg, 2014	247, 250	...a wall block system consisting of rectangular blocks (400 x 300 x 100mm)... stand out for their freedom in wall composition .		X								
Gijsbers and Lichtenberg, 2014	247, 250	The blocks are fixated using removable adhesive strips ...						X				
Gijsbers and Lichtenberg, 2014	250	In general, less coupling means less effort to perform adaptations in practice.						X				
Gijsbers and Lichtenberg, 2014	250	Wiring... is... partly embedded in the concrete flooring... a hollow floor that contains freely dividable installation space is preferable...						X				
Gosling et al., 2013	46	... layering involves dividing the building elements... so these can be maintained or adapted without affecting ... other layers...						X				
Gosling et al., 2013	46	... separates a ‘base-building’ and its interior ‘fit-out’, which should be able to be installed or changed with a minimum of interface problems ...						X				
Gosling et al., 2013	46-47	Overcapacity ... can be applied effectively to the structure, services systems and space standards to make buildings more adaptable...	X									

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Gosling et al., 2013	47	...it can only be adapted easily if the <u>integration</u> of the components allows for the <u>component removal</u> from the building.					X					
Gosling et al., 2013	47	Accessible floors and ceiling systems that facilitating services adaptations are <u>standard</u> sizes and <u>interchangeable</u> .		X								
Gosling et al., 2013	47	...the more <u>open plan</u> the building is the more permutations of internal layouts are possible.	X									
Gosling et al., 2013	47	... <u>building width</u> and <u>floor to floor height</u> contribute to... the ability to meet changing user or owner needs without changing its properties.	X									
Gosling et al., 2013	48	Adaptable buildings would allow service plant... to be removed from the building through <u>suitably sized openings</u> that allow safe access...						X				
Gosling et al., 2013	48	The use of <u>standard components</u> means that elements no longer needed in one building <u>can replace</u> obsolete elements in <u>another</u> .		X								
Greden and Glicksman, 2005	38	...the building with <u>extra</u> floor-to-ceiling height... so as to have the flexibility to convert to office space at a modest cost.	X									
Greden and Glicksman, 2005	38	...the building with... <u>removable</u> spandrel glass so as to have the flexibility to convert to office space at a modest cost.					X					
Greden and Glicksman, 2005	40	...an office space with a <u>moveable</u> wall system has a low renovation cost to convert...					X					
Grover and Grover, 2015	301	...obsolescence is unsystematic requiring investors to <u>diversify</u> their portfolios if they are to mitigate its consequences...			X							
Grover and Grover, 2015	305	...identified as important were the... internal specifications... and <u>configuration</u> , which is the <u>horizontal</u> ... layout of a building.	X									
Grover and Grover, 2015	305	...identified as important were the... internal specifications... and <u>configuration</u> , which is the... <u>vertical</u> layout of a building.	X									
Grover and Grover, 2015	308	<u>Iconic</u> buildings may be adapted..., either because their <u>aesthetic features</u> ... or because... demolition... will not be forthcoming.									X	
Grover and Grover, 2015	309	A <u>shell</u> is capable of being re-used...	X									
Grover and Grover, 2015	309	...an <u>integrated</u> system cannot... [be re-used]					X					
Grover and Grover, 2015	309	...a cinema may become a bingo club and then a church... the building was designed... [with] <u>characteristics required by each of its subsequent uses</u> .				X						
Grover and Grover, 2015	309	...a <u>prison</u> may be converted into a <u>hotel</u> ... the building was designed to provide <u>residential accommodation</u> but <u>not permanent</u> residence.				X						
Halvitigala and Reed, 2015	483	... <u>smaller</u> floor plates are in decreasing demand... any future alternations would be restricted by the floor plates...	X									
Halvitigala and Reed, 2015	485	...structures were... based on a <u>modular</u> concept with <u>consistent</u> floor to ceiling height... for increased flexibility and an efficient use of space.		X								
Halvitigala and Reed, 2015	485	...floor plates deeper than 20 m were considered inefficient as it may cause <u>lighting and ventilation issues</u> .				X						

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Halvitigala and Reed, 2015	485	It was suggested that increased floor-to-floor heights <u>enhanced lighting, ventilation</u> and the " <u>feeling</u> " of space.				x						
Halvitigala and Reed, 2015	485	...a high level of flexible buildings using <u>higher</u> floor to ceiling heights...	x									
Halvitigala and Reed, 2015	485	...a high level of flexible buildings using... <u>soundproof</u> suspended ceilings...	x									
Halvitigala and Reed, 2015	485-486	Improved floor plate efficiencies were achieved by... <u>large</u> ... floor plates with <u>large</u> vertical risers...	x									
Halvitigala and Reed, 2015	485-486	Improved floor plate efficiencies were achieved by... <u>uninterrupted</u> floor plates...		x								
Halvitigala and Reed, 2015	485-486	Improved floor plate efficiencies were achieved by... <u>simple geometrically</u> shaped floor plates...				x						
Halvitigala and Reed, 2015	485-486	Improved floor plate efficiencies were achieved by... <u>good natural light penetration</u> throughout the floor plate.				x						
Halvitigala and Reed, 2015	486	...the shape of floor plate... where <u>simple geometric shapes</u> , such as <u>squares</u> or <u>rectangles</u> , were used to improve spatial efficiency.				x						
Halvitigala and Reed, 2015	486	...the majority of service cores... were <u>along one edge</u> of the building perimeter... to provide more flexibility relating to maximum depth...	x									
Halvitigala and Reed, 2015	486	...more <u>natural</u> light and ventilation were used to enhance efficiency in building services.				x						
Halvitigala and Reed, 2015	486	...the AC system... is serviced on a <u>part-floor</u> basis, so after hours the AC is on only in one zone instead of the whole floor...		x								
Halvitigala and Reed, 2015	487	...to develop... properties that have " <u>unique</u> characteristics with designs of the highest <u>aesthetic quality</u> and sense of pride for occupiers"...									x	
Halvitigala and Reed, 2015	487	At the same time, <u>over-specification</u> and <u>over-complication</u> of building design and specifications were avoided...				x						
Halvitigala and Reed, 2015	487	...the IT networks in their office buildings were <u>divided into zones</u> so each zone can perform <u>independently</u> ...		x								
Halvitigala and Reed, 2015	487	...the cabling... were installed using "low profile raised floor system" and can be <u>easily accessed</u> ...						x				
Halvitigala and Reed, 2015	487	...to facilitate the... <u>reticulation</u> of data... so tenants <u>can take data</u> from the demarcation point <u>in the basement up through the risers</u> and <u>round the building</u> through the perimeter duct system".		x								
Halvitigala and Reed, 2015	487-488	...ceilings with <u>high-noise</u> reduction co-efficient and <u>high-articulation</u> class values were used... So when you go to an open plan office environment they are much quieter now".	x									
Halvitigala and Reed, 2015	488	...interior partitions could be easily dismantled and removed where <u>complex partitions</u> and...were avoided...									x	
Halvitigala and Reed, 2015	488	...interior partitions could be easily dismantled and removed where <u>complex</u> ... and <u>building specifications</u> were avoided...				x						
Hamraz et al., 2013	142	...the <u>dependencies</u> between component pairs to compute the overall risk of change propagation imposed on other components...					x					

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Hassanain, 2006	214	...giving high flexibility in office buildings are... plug and play building elements which allows for fast changes of layout...						X				
Hassanain, 2006	214	...giving high flexibility in office buildings are flat ... ceiling for rapid and easy moving of internal walls...	X									
Hassanain, 2006	214	...giving high flexibility in office buildings are... soundproof ceiling for rapid and easy moving of internal walls...	X									
Hassanain, 2006	217	Keeping the design of the building simple : designers should avoid... over-complication ...									X	
Hassanain, 2006	217	...designers should avoid over-specification ... and design based on short-lived quick-fix technologies.				X						
Hassanain, 2006	217	A shell and core approach makes it easier to adapt areas of the building to individual corporate client needs.	X									
Hassanain, 2006	217	Designing on a grid basis , for example, a planning grid of 1.5m, provides for good flexibility (Brittain et al., 2004).		X								
Hassanain, 2006	217	...simplifying the range of settings ... The trend for providing office space should be a single office size , rather than two or three sizes .		X								
Hassanain, 2006	217	Designing larger vertical risers, and larger ... floor plates suited to mixture of open-plan and cellular space (Markland, 1998).	X									
Hassanain, 2006	217	Designing... uninterrupted floor plates suited to mixture of open-plan and cellular space (Markland, 1998).	X									
Hassanain, 2006	217	...using walls of offices that are mobile ones, that is merging or separation of units can be managed by little effort .					X					
Hassanain, 2006	218	...Designing building services with overcapacity only where it is too expensive to add in later.	X									
Hassanain, 2006	218	...being aware of over-congested services by leaving space to alter ... the service in the future.						X				
Hassanain, 2006	218	...being aware of over-congested services by leaving space ... add to the service in the future.	X									
Hassanain, 2006	218	Systems should be able to operate on a part-floor basis where large floor plates are designed.		X								
Hassanain, 2006	218	IT networks should be divided into separate zones so that each zone can perform independently ...		X								
Hassanain, 2006	218	The telecommunication infrastructure should be built to be replaced or renovated easily with a minimum damage to the main structure...					X					
Hassanain, 2006	218	...to recast shared settings as multi-use (flex) facilities, for example, conference centers, lunchroom or cafés, meeting room and libraries...		X								
Hein and Houck, 2008	124	...alterations to a structure can be hazardous, although... the original concrete frame was over-designed for the... loads of warehouse floors...	X									
Hertzberger, 2014	108	...generic space would seem the best antidote... Yet we should not simply strip architecture of all its qualities and meanings... Architecture must always have that competence, availed as it were of an inherent charge that can generate specific responses to each new situation.	?	?	?	?	?	?	?	?	?	?

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Hertzberger, 2014	109	...polyvalence entails introducing the greatest number of spatial conditions that can <u>play a part in every situation</u> ... [they] arouse and incite them to a more intensive use of space...			x							
Hertzberger, 2014	110	...of polyvalent space, we can articulate a floor surface area as <u>separated repeated</u> space units. Thus, for example... [a building] consists of the <u>consistent repetition</u> of a single-space unit of 9 x 9 metres...			x							
Hertzberger, 2014	112	...polyvalence... a quality that gives people <u>a reference point</u> and even incites them to turn their living environment into familiar ground...										x
Hertzberger, 2014	112	That quality can be achieved... by making them [partitions] fundamentally inclusive. And this requires... <u>depth</u> ...	x									
Hertzberger, 2014	112	That quality can be achieved... for the space unit to be able to take up ever-new content and still <u>remain itself</u> ...									x	
Hertzberger, 2014	113	...we should abstain from <u>over-specific</u> and <u>over-expressive</u> fabrications...				x						
Hertzberger, 2014	113	Architects must provide... buildings with <u>character</u> , explicit, recognisable, authentic, original yet without imposing a particular taste...									x	
Hunter, 2006	65	...new... spaces should... not be limited by the physical structure of the building with the ever increasing use of learning technologies they do expand beyond the physical space.	?	?	?	?	?	?	?	?	?	?
Hunter, 2006	65	...predicting what technologies might be used in the future is difficult, so robustness as well as flexibility is important.	?	?	?	?	?	?	?	?	?	?
Hunter, 2006	68	...video surveillance of users, swipecard access locks, radio frequency identification tagging... most of these 'locks' degrade the environment, especially in terms of flexibility and <u>ease of use</u> .						x				
Hunter, 2006	71	The <u>fusion of</u> library spaces, open access learning spaces and teaching spaces... <u>Bringing these together</u> into a single building...			x							
Hunter, 2006	71	... [This] also facilitates ' <u>multiple-uses</u> ' of rooms, with teaching and meeting rooms <u>doubling up as</u> group or individual work areas...			x							
Hunter, 2006	72	...providing <u>spacious</u> and flexible areas for students...	x									
Hunter, 2006	72	By creating a flexible space with <u>easy access to power, data and infrastructure</u> , the university hopes to embrace the 'unexpected'...			x							
Hunter, 2006	73	...the <u>restrictions</u> imposed by the building have been turned to advantage...	x									
Hunter, 2006	73	[They] <u>break-up the space</u> and provide some separation of groups <u>without subdividing the space</u> .			x							
Hunter, 2006	73-74	<u>Moveable</u> acoustic screens act as ad-hoc dividers and help to manage the noise levels.					x					
Isaac et al., 2014	275	...adaptability of buildings through the systematic <u>separation</u> of building components with different replacement rates.					x					
Isaac et al., 2014	275	...modularization of the design can reduce the <u>interdependencies</u> between construction activities...					x					

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Isaac et al., 2014	275	The <u>standardization</u> of the interfaces between modules... makes it easier to accommodate the user's requirements...		x								
Isaac et al., 2014	275	[it is] ...easier to accommodate the user's requirements... through <u>a large number of different types</u> of modules.			x							
Isaac et al., 2014	278	...buffers are applied by designing components with a capacity <u>larger</u> than that required... This <u>extra capacity</u> can be used in the future...	x									
Isaac et al., 2014	278	...when components <u>connect too large a number</u> of other components, <u>relationships</u> can be reduced through modularization...					x					
Isaac et al., 2014	278	... <u>relationships</u> can be reduced through... <u>easily disconnected</u> interfaces.						x				
Israelsson and Hansson, 2009	140	Materials with a life suitable for both existing and future activities create flexibility in buildings...	?	?	?	?	?	?	?	?	?	?
Israelsson and Hansson, 2009	140	One small error in manufacturing can result in consequences for future rebuilding and therefore affect flexibility.	?	?	?	?	?	?	?	?	?	?
Israelsson and Hansson, 2009	141	Modern installations generally <u>take up more space</u> ... the problem arises because of difficulty in changing installations.	x									
Itard and Klunder, 2007	256	The <u>load-bearing structure</u> ... <u>do not preclude</u> implementing new technical solutions to attract new target groups.		x								
Itard and Klunder, 2007	256	The... and <u>dimensions do not preclude</u> implementing new technical solutions to attract new target groups.	x									
Itard and Klunder, 2007	266	...by using construction that does not depend on <u>load-bearing inner walls</u> , enabling the walls to be removed easily.		x								
Itard and Klunder, 2007	266	<u>Significant space</u> between <u>load-bearing elements</u> ... also facilitate redesign of housing blocks and buildings.		x								
Itard and Klunder, 2007	266	... <u>floor height</u> also facilitate redesign of housing blocks and buildings.	x									
Khan and Dhar, 2012	48	...a great variety of family types can live in the same <u>shell</u> or one... can also change layouts of the same shell according to their changing needs		x								
Khan and Dhar, 2012	49	The location... of the <u>columns</u> or <u>structural shear wall</u> determines the possibility to expand spaces inside.		x								
Khan and Dhar, 2012	49	Façade Envelop has window zones and <u>windowless zones</u> , which can limit the possibility of re-arranging layouts in case of transformation.				x						
Khan and Dhar, 2012	50	Private flats usually did not come as <u>empty shells</u> ... Therefore, these housing units were assumed to be less flexible...		x								
Khan and Dhar, 2012	50	...flexibility of <u>shells</u> was gradually reduced... <u>Structural walls</u> invaded the freedom <u>at infill level</u> .		x								
Khan and Dhar, 2012	54	... <u>column, shear walls</u> , and beams (i.e. the 'support' elements) <u>may limit</u> the options to transform internal spaces.		x								
Khan and Dhar, 2012	56	...the units can have <u>variety in sizes</u> . Therefore they have more potential for flexibility in one single block.			x							
Khan and Dhar, 2012	57	...partition walls... are <u>equipped with</u> different concealed wiring and piping; therefore it makes difficult for users to make changes in layout...					x					

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Khan and Dhar, 2012	57	...the way the partition walls or the infill are constructed in-situ, later transformations increase <u>construction hazards</u> ...						X				
Khan and Dhar, 2012	57	The <u>absence of shear wall or column</u> on the sharing wall is therefore an advantage for that kind of transformation.	X									
Khan and Dhar, 2012	58	The increased rigidity in layouts can be compensated by the <u>variety</u> offered <u>in sizes</u> ... it is probably easier to decide to move.			X							
Langston and Shen, 2007	200	The building being largely <u>open design</u> would attract a low churn cost for alterations...	X									
Langston et al., 2008	1711	It is wise to design future buildings for change... with <u>sufficient</u> structural integrity to support alternative functional use.	X									
Langston et al., 2008	1716	The building being of largely <u>open design</u> would attract a low churn cost for alterations...	X									
Lin, 2011	13	supporting a total of 144 <u>interchangeable</u> "capsules"... Each capsule houses a <u>self-contained</u> residential unit... showcasing... adaptability...		X								
Lin, 2011	19	Each capsule is tied to one of the concrete cores with <u>only four high-tension bolts</u> ... That means that every unit is removable...					X					
Lin, 2011	19	Each capsule was installed <u>independently</u> and cantilevered from the shaft so that it could be removed without affecting others.					X					
Lin, 2011	21	...the floor/area ratios of Metabolist buildings are often <u>below average</u> , making them less economically viable.				X						
Mantab-uz-Zaman, 2011	48	...residential conversion is the best option for... [those] which were built in <u>strong load bearing structures</u> that can easily be remodelled.							X			
Mantab-uz-Zaman, 2011	48	...prerequisites to... adaptable building... the <u>architectural or historic quality</u> of the building...									X	
Mantab-uz-Zaman, 2011	48	...prerequisites to... adaptable building... [the] <u>potential market demand</u> ...				X						
Mantab-uz-Zaman, 2011	52	...the original construction method poses challenge in reconstruction works as buildings often are made of <u>load bearing construction walls</u> .	X									
March et al., 2012	547	...reducing its score were <u>excessively small</u> floor size... <u>awkward plan shapes</u> and difficult service core locations...				X						
March et al., 2012	547	...redeeming features... were that many had <u>site access on 2 sides</u> ...						X				
March et al., 2012	547-548	The majority of buildings in Case B have floor areas greater than 700 m2 and <u>large</u> adaptable floor plans...	X									
March et al., 2012	547-548	...despite negative features of many of the buildings... <u>excessively wide</u> street frontages.				X						
March et al., 2012	548	Plan shape: <Deep plan (1)> <Irregular (0.8)> < <u>Narrow</u> frontage (0.6)> < <u>Wide</u> plan (0.4)> < <u>Curved</u> (0.2)>				X						
March et al., 2012	548	Site boundaries: < <u>None</u> (1)> ... <Bounded on 3 sides (0.4)> < <u>Bounded on all sides</u> (0.2)>		X								
March et al., 2012	548	<u>Access to building</u> : <Access all sides (1)> <Street and side access (0.8)> <Street and rear access (0.6)> <Street only (0.4)>						X				

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March et al., 2012	548	Height of building (storey): <6 or less (1)> <7-20 (0.2)> <21-45 (0.4)> <46 above (0.1)>					x					
March et al., 2012	548	Building width (metres): <20 m (0.1)> <20.01–40 m (0.5)> <40.01–60 m (1)> <60.01–201.25 m (0.5)>					x					
March et al., 2012	548	Floor size: <Small (0.5)> <Large (<700 m2)(1)>	x									
March et al., 2012	548	Type of construction: <Steel/Concrete (0.08)> <Other (0.92)>	?	?	?	?	?	?	?	?	?	?
March et al., 2012	548	Service core location: <Central (1)> <Dual locations (0.5)> <Other (0.1)>			x							
March et al., 2012	551	...factors that... assist with adaptability, such as <u>large</u> floor plates...	x									
March et al., 2012	551	...factors that... assist with adaptability... may... hinder adaptation over time when they are associated with low levels of land use <u>mix</u> .			x							
Meins et al., 2010	287-288	...are a response to future changes... which are not foreseeable today... it cannot yet be foreseen today which technological developments <u>will make it necessary to lay new</u> cables...	x									
Meins et al., 2010	292	Flexibility and Polyvalence Can be improved through: - <u>Sufficiently wide</u> aisles - Wheelchair accessible restrooms	x									
Nijs et al., 2011	35	Ideally, <u>independency</u> ... is required, which achieves that building levels can be adapted <u>separately</u> , resulting in more freedom to change.					x					
Nijs et al., 2011	38	If flexibility is to be achieved, it is necessary to design every level <u>apart from one another</u> .					x					
Nijs et al., 2011	39	indirect [connection] with additional fixing devices: with change of one element <u>another stays untouched</u> ...					x					
Nijs et al., 2011	41	...an indirect connection by using... [a] component such as a <u>clamp or click connection</u> . This offers the facility <u>to detach/replace... easily</u> ...						x				
Paslawski and Rozdzyńska, 2013	884	...pertains to consideration of the possibility to implement changes (<u>expansion should be considered as a standard</u> ...	x									
Paslawski and Rozdzyńska, 2013	884-885	...designing heating equipment so as to enable using <u>different</u> fuels during the operation of the heating system (fuel <u>options</u>).			x							
Pinder et al., 2013	441	...constructing for a high level of adaptability in office buildings, using solutions such as <u>higher</u> floor-to-ceiling heights...	x									
Pinder et al., 2013	441	...constructing for a high level of adaptability in office buildings, using solutions such as... <u>soundproof</u> suspended ceilings...	x									
Pinder et al., 2013	442	...specification that involved <u>over-specifying</u> ... ultimately... resulted in <u>more expensive</u> and more energy intensive office buildings...					x					
Pinder et al., 2013	443	...adaptability in office buildings can be enabled by ensuring that they have <u>more generous</u> floor plans and storey heights...	x									
Pinder et al., 2013	448	... <u>over-specifying</u> floor loadings is great... [otherwise] you affect the <u>floor loadings</u> and you can't let the shop because you <u>can't put a book store in</u> ...	x									

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Pinder et al., 2013	448	...we try to cater or provide a degree of flexibility for spatial changes so we <u>over-provide</u> because it's a lot easier... at day one...	X									
Pinder et al., 2013	450	...office buildings that can be converted... a developer would end up with either <u>sub-optimal</u> offices or sub-optimal housing.				X						
Pinder et al., 2013	450	... 'good buys'; low cost solutions that are almost certain to be used in the future,... the <u>overprovision</u> of power outlets in a retail scheme.	X									
Pinder et al., 2013	450	... 'luxuries'... expensive and there is uncertainty... whether they will ever be utilized... <u>oversized</u> foundations and <u>increased</u> storey heights.	X									
Pinder et al., 2013	450	... 'cheap tricks'... <u>included lintels</u> ... into the design of an external wall to allow new openings to be made in the future.	X									
Pinder et al., 2013	450	... 'lifesavers'... providing <u>additional</u> plant room [service space] <u>capacity</u> to support an increase in the number of building users...	X									
Pinder et al., 2013	451	... 'I'm going to do the whole thing in <u>load bearing masonry</u> with <u>short spans</u> .' and then actual flexibility of use is limited... (Architect #2)		X								
Pinder et al., 2013	453	...because they were considered to be <u>less durable</u> ... and were therefore difficult to change.								X		
Pinder et al., 2013	453	...because they meant that building components were <u>melded together</u> and were therefore difficult to change.					X					
Remøy and van der Voordt, 2014a	384	Post-war office buildings were designed to fit closely around the function... This <u>tight fitting</u> threatens... feasibility of conversion...	X									
Remøy and van der Voordt, 2014a	387	Office buildings are constructed <u>to bear more</u> weight... and in most cases additional floors could be carried by the existing structure.	X									
Remøy and van der Voordt, 2014a	387	...before 1965, floors were <u>penetrated</u> and shafts were placed <u>without problems</u> . After 1965, pre-stressed concrete was commonly used... [it] loses strength when the <u>steel</u> is cut.			X							
Remøy and van der Voordt, 2014a	388	The <u>large number of columns</u> in older offices may cause a partition problem for conversions.		X								
Remøy and van der Voordt, 2014a	388	...using pre-stressed concrete floors... makes it difficult to add vertical shafts. The steel cables <u>in the floors</u> may be located, but are <u>not always located on the same place</u> in all floors.										X
Remøy and van der Voordt, 2014a	388	<u>Beams</u> under the floors <u>may cause problems</u> , because the effective height is incidentally lowered, thus creating a challenge for fitting new installations and services...		X								
Remøy and van der Voordt, 2014a	388-389	The acoustic insulation of typical office floors is <u>not sufficient</u> for housing. In most conversions... requires <u>additional</u> acoustic insulation...	X									
Remøy and van der Voordt, 2014a	389	Office buildings are designed <u>for more</u> people per m2 and more traffic... Therefore, an <u>excess</u> number of lifts is a positive aspect...	X									
Remøy and van der Voordt, 2014a	389	...with <u>cantilevering floors</u> and a curtain wall facade. Such a structure makes the addition of balconies difficult.			X							

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Remøy and van der Voordt, 2014a	389	The building depth may be an obstacle for the conversion... buildings from the 1960s were generally deep and <u>with little daylight access</u> .					X					
Remøy and van der Voordt, 2014a	389	In most cases, office buildings have <u>higher</u> storeys <u>than required</u> for residential...	X									
Remøy and van der Voordt, 2014b	142	...the main push factors in the selection of office accommodation... [One of which is] <u>Lack of</u> expansion space.	X									
Remøy and van der Voordt, 2014b	142	...a <u>spatially comfortable</u> entrance...was found to decrease the odds of structural vacancy... Entrances with relatively low ceilings and large surfaces are... <u>low and unpleasant</u> ...					X					
Remøy et al., 2011	444	...By such a <u>division</u> into layers, each layer can be adapted, replaced or removed <u>without influencing</u> the other building layers.						X				
Remøy et al., 2011	449	Extendibility – Horizontal: <u>Columns in the façade</u> allow for balconies or small additions.			X							
Remøy et al., 2011	449	Extendibility – Vertical: Normally two floors may be added as office buildings are constructed <u>to carry more weight</u> than housing.	X									
Remøy et al., 2011	449	<u>Monolithic</u> post-stressed floors make it possible to apply shafts after completion, as opposed to the standard precast hollow beam floor slabs.			X							
Remøy et al., 2011	449	...Height: 3.6 metres is the standard height (floor-to-floor) for offices and <u>leaves room</u> for transformation into housing...	X									
Remøy et al., 2011	449	Façade – Replaceable: <u>Not load bearing</u> , easily demountable, replace or adapt to be decided if transformed.		X								
Remøy et al., 2011	452	The adaptability of office buildings is determined by the buildings... <u>separation</u> of the <u>different layers</u> like façade and installations.						X				
Ren et al., 2014	33	... <u>low ceilings</u> in many industrial buildings make them functionally obsolete today...	X									
Ren et al., 2014	33	...corridors can prove to be costly... commercial buildings <u>often have wide corridors</u> , which <u>can consume valuable</u> guest room <u>space</u> .					X					
Ren et al., 2014	33	... <u>thick concrete slabs</u> ... may <u>add to redevelopment costs</u> , especially if plumbing has to be added...						X				
Ren et al., 2014	35-36	... [they] were constructed to <u>much</u> higher loading levels than required for... hotel developments... The <u>thicker floors drove up</u> ... <u>costs</u> ...					X					
Ren et al., 2014	36	...these buildings were clustered... which generated a big problem... since <u>windows and views</u> were key elements to hotel design.					X					
Ren et al., 2014	36	...all industrial buildings... were constructed <u>right up to the boundary line</u> , and that <u>adding</u> a curtainwall... meant changing gross floor area.	X									
Ross et al., 2016	421	The... <u>separation</u> of elements allows for maintenance, adaptation, or replacement with <u>minimized effect</u> on other elements.						X				
Ross et al., 2016	422	Accordingly, buildings can be initially designed to accommodate a potential <u>increase in future loads</u> ...	X									

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Ross et al., 2016	422	...simple mechanical connections can <u>enable</u> the removal and addition of components... Composite glues/welds <u>can be difficult</u> to remove...						X				
Ross et al., 2016	422	The use of fewer but larger members results in <u>fewer connections that must be disassembled</u> and increases the likelihood of salvageability.					X					
Ross et al., 2016	422	...designing a <u>straightforward</u> load path can help future designers <u>understand</u> which members are critical for structural integrity...									X	
Ross et al., 2016	422	...to facilitate assessment procedures that do not <u>negatively interfere</u> with components adjacent to the one in question [11–13].					X					
Ross et al., 2016	422	...to <u>facilitate assessment</u> procedures... Remote sensing... can be used... in lieu of <u>visual inspection</u> .									X	
Ross et al., 2016	423	Children's plastic building blocks, which are <u>interchangeable</u> and can be combined to create a variety of forms due to <u>standardization</u> ...		X								
Ross et al., 2016	423	<u>Repetitive use</u> of... components and details <u>helps to create</u> replacement and adaptation <u>schemes</u> that can be systematically reused...									X	
Ross et al., 2016	423	Buildings containing <u>harmful materials</u> (e.g., asbestos) are less attractive for adaptive reuse...					X					
Ross et al., 2016	423	<u>Open plan</u> layouts, <u>free of</u> structural, mechanical, and other <u>obstructions</u> , allow for adaptation of interior spaces...	X									
Ross et al., 2016	424	...effective enablers are... <u>reserve capacity</u> in the building systems...	X									
Ross et al., 2016	424	...effective enablers are... <u>separation of building systems</u> ...					X					
Ross et al., 2016	424	...effective enablers are... interior spaces that are <u>free of structural</u> and other elements that cannot be easily removed...	X									
Saari et al., 2007	106	...flexibility can be promoted through... adjustable spaces... including ventilation <u>systems that can be regulated</u> for different uses.				X						
Saari et al., 2007	106	... <u>dividing</u> and combining subsystems in a way that minimizes their <u>interdependencies</u> by transforming subsystems without redesigning...					X					
Saari et al., 2007	113	...not... over-dimensioning... [instead] The... building must be dimensioned to allow for the range of variation of room programmes.	?	?	?	?	?	?	?	?	?	?
Saghafi and Ahmadi, 2011	660	...buildings <u>with less density</u> are demolished and replaced by... buildings that <u>offer more profits</u> due to higher price of land.				X						
Saigo et al., 2011	5	... <u>sliding partitions</u> that can be <u>effortlessly</u> opened and closed to instantly alter room configurations to suit the occasion...					X					
Saigo et al., 2011	5	...instantly alter room configurations to suit the occasion... [as opposed to] western cultures where <u>load-bearing walls</u> are the norm...	X									
Saigo et al., 2011	6	Why are these... so easy to renovate and expand?... <u>post-and-beam</u> structure, which fundamentally differs from the <u>load-bearing wall</u> ...	X									
Saigo et al., 2011	6	...a very flexible system, unlike the trussed roofs used in western designs. With the wagoya roof, struts <u>are built atop</u> the beams...					X					
Saigo et al., 2011	6	Hipped roofs built on this system can shed rainwater extremely well, <u>no matter how complex the exterior form</u> of the building...	X									

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Saigo et al., 2011	7	With the wagoya system... roofs can be constructed with... <u>few special components</u> , and most of the parts can be reused in renovation.		x								
Saigo et al., 2011	8	Structural components have to be replaced from time to time... to facilitate this process a concept of modular coordination (MC), i.e., <u>standardization</u> of components...		x								
Saigo et al., 2011	10	...relatively few wooden buildings dating from the... late 8th to late 12th century) survive today... The reason... is that their pillars are <u>thicker</u> and their nageshi... are more <u>robust</u> ...								x		
Saigo et al., 2011	15	Because the sizes are not <u>standardized</u> ... replacement of these components... often requiring replacement of doorframes...		x								
Schmidt III and Eguchi, 2014	77	...to construct buildings that could be changed easily through the use of <u>lightweight</u> materials...						x				
Schmidt III and Eguchi, 2014	77	...to construct buildings that could be changed easily through the use of... ' <u>non-permanent</u> ' <u>physical connections</u> .						x				
Schmidt III and Eguchi, 2014	77	Change is further enabled with the structural design as a <u>framed system</u> of thin columns...	x									
Schmidt III and Eguchi, 2014	77	...with the structural design as a framed system of <u>thin</u> columns..., beams and trusses (wagoya) that can easily be removed or added.						x				
Schmidt III and Eguchi, 2014	77	<u>Ample</u> storage space, oshiire, is another important aspect as all furniture is storable.	x									
Schmidt III and Eguchi, 2014	77	...by <u>light</u> , double <u>sliding partitions</u> and windows... which are easy to shift, remove and store.						x				
Schmidt III and Eguchi, 2014	78	...the buildings were made up of subsets of components... these... approaches were felt <u>too complex to be easily disseminated</u> ... [later] the skeleton-infill (SI) system was introduced... <u>simplified approach</u> ...										x
Schmidt III and Eguchi, 2014	79	The <u>generous</u> floor-to-floor heights... provide sufficient space for services, increased storage...	x									
Schmidt III and Eguchi, 2014	79	To avoid standard handrails, counters and tables were installed at an <u>appropriate height</u> ... along with a handrail-shaped wooden wall component <u>that can also be used as</u> a shelf.		x								
Schmidt III et al., 2014	162	... <u>isolating</u> discrete functions or systems within chunks, makes it possible to 'change pieces of a system <u>without redoing the whole</u> .					x					
Schmidt III et al., 2014	162	...the need to reduce chunk sizes into <u>manageable dimensions</u> ...						x				
Schmidt III et al., 2014	162	...the advantage of combining chunks with functional purposes, thus <u>reducing</u> inter-modular complexity and <u>interfaces</u> .					x					
Schmidt III et al., 2014	164	...the more <u>layers are connected</u> , the greater difficulty and cost of adaptation (Brand, 1994).					x					
Schmidt III et al., 2014	180	<u>Volumetric solutions</u> , such as the bathroom pod (22), <u>provide difficulty</u> in regard to future change in terms of removal...						x				
Schmidt III et al., 2014	180	Binding the electrical cables (16) with the structural frame (4) creates a significant problem in terms of <u>layer separation</u> and access for future change.					x					

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Schmidt III et al., 2014	181	...bolts and fasteners... require <u>additional work</u> ... compared to other connection methods (e.g. plug 'n' play).					X					
Schwehr, 2011	20	...apartments with specific solutions for a <u>specific way of life</u> are at an evolutionary dead end.				X						
Schwehr, 2011	20	<u>equal</u> rooms = adaptable, specific rooms = not adaptable		X								
Schwehr, 2011	22	Flexible buildings have a number of concepts which can react individually to their context. <u>Variance</u> makes it possible to... be "fitter"...			X							
Schwehr, 2011	23	Flexible buildings have <u>predetermined breaking points</u> to allow building parts and systems... to be exchanged with little effort.					X					
Schwehr, 2011	23	Margin of error:... buildings are fault tolerant and <u>not highly specified</u> .				X						
Slaughter, 2001	213	...physically <u>separating</u> the major building systems... so that changes in one area can be <u>isolated</u> from changes in other regions...					X					
Slaughter, 2001	213	... <u>overcapacity</u> so that changes can be accommodated without the replacement or extension of current capacity capabilities...	X									
Slaughter, 2001	213	...a new interior partition system uses prefabricated panels that fit into a ceiling mounted track, with <u>no</u> required <u>on-site activities</u> to...						X				
Slaughter, 2001	214	...components may <u>aggregate</u> several smaller units <u>together</u> ... [e.g.] raised panelized floor with data interface boxes attached... with <u>movement of the</u> special <u>panels thereby relocating the boxes</u> ...					X					
Slaughter, 2001	214	...reduce the <u>interdependency</u> with other systems... [so that] one system can be changed <u>without required alterations in other systems</u> .					X					
Slaughter, 2001	214	...a <u>modular</u> block partition wall provides... easily move the doorway... through simply <u>re-arranging the blocks</u> ...		X								
Slaughter, 2001	215	...regularity of the physical layout can provide critical <u>signals</u> to reduce the duration and... demolition to find the required components.									X	
Slaughter, 2001	215	...improving the physical access [e.g.]... <u>demountable</u> drywall panels that <u>provide easy access</u> to the electrical wiring within the wall cavity.						X				
Slaughter, 2001	215	...to create <u>specific zones for each particular system</u> , and to keep those areas or volumes free from other components and systems...									X	
Slaughter, 2001	215	...the <u>physical proximity</u> of... [electrical] systems were set out... below the suspended floor so the access points could be easily repositioned...					X					
Slaughter, 2001	215	...the building cores... can be placed at either end of the building <u>to open</u> the centre of the floor plate as useable space.		X								
Steadman, 2006	127	...in the flexibility of <u>assigning different dimensions</u> to those configurations [of rectangles], while <u>preserving their rectangularity</u> .		X								
Steadman, 2006	127	...this flexibility from another point of view: it is always possible to divide <u>any rectangle</u> within a packing <u>into two rectangles</u> ...		X								
Sung-Hwa and Beisi, 2012	20, 21	Originally, there were four pieces, but later on, <u>three out of the four</u> doors were <u>made into one</u> for the <u>convenience of easy lifting</u> .					X					
Sung-Hwa and Beisi, 2012	22	...the walls were <u>lightweight</u> partitions <u>operable like doors or windows</u> ... accommodating the changes in use in everyday life.						X				

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Sung-Hwa and Beisi, 2012	22	Each room had a separate exit outside, which could be used as an <u>independent</u> space.		X								
Sung-Hwa and Beisi, 2012	23	... <u>only a few</u> essential pieces of furniture that occupied space along walls, <u>leaving the middle of the room free</u> for... various activities...	X									
Sung-Hwa and Beisi, 2012	23	To accommodate the multiple uses of a small room, the <u>furniture</u> and <u>decoration</u> in sarangbang were <u>minimized</u> ...		X								
Sung-Hwa and Beisi, 2012	25	...was <u>easily repaired</u> by replacing... components... It was built... <u>without any nails</u> .						X				
Sung-Hwa and Beisi, 2012	25	By trimming timber with <u>specific measurements and forms</u> ... This prefabrication method <u>facilitates the replacement</u> of elements...		X								
Vandenbroucke et al., 2015	539	...because the frames have been designed to support up to three storeys [22] <u>[overcapacity]</u> ... the frames can be completely reused...	X									
Vandenbroucke et al., 2015	546	...to these <u>dry and reversible connections</u> ... changes can be made <u>in a simple way</u> without generating additional construction waste.						X				
Vandenbroucke et al., 2015	546	<u>Commonly used</u> materials were chosen to enable frequent reuse... such as plywood instead of gypsum boards.				X						
Vimpari and Junnila, 2016	347	... <u>interaction between</u> building <u>systems</u> ... strongly influenced the building's adaptability...					X					
Vimpari and Junnila, 2016	349	...to switch... office space into retail use... The costs are... whether the <u>ground floor slabs</u> and <u>ceiling heights can suit</u> future retail use...	X									
Vimpari and Junnila, 2016	349	...whether the plan layout and mechanical services can ensure that the retail premises <u>operate independently</u> of upper floor offices.		X								
Walker, 2010	816	...each time materials are processed and combined... they become <u>increasingly complex</u> ... making their recycling... more problematic.										X
Walker, 2010	821	...these two sets of components have only a <u>loose connection</u> , allowing them to be <u>easily separated</u> for purposes of... and change.						X				
Walker, 2010	821	...because they are <u>standard, off-the-shelf parts</u> , they can be easily replaced when the need arises.				X						
Walker, 2010	829	...local manufacturing and services would <u>allow people to better understand</u> the nature of their material products...										X
Walker et al., 2013	957	...ways for dealing with deep uncertainty in making sustainable plans [12]: • resistance: plan for the <u>worst possible case</u> or future situation...	X									
Walker et al., 2013	958	A robust plan is defined to be one that yields outcomes that are deemed to be satisfactory... <u>across a wide range</u> of future plausible states...			X							
Wiendahl et al., 2007	788	...this enabler allows incorporating or disconnecting products, product groups and work pieces... with little effort, by using <u>uniform</u> interfaces.		X								
Wiendahl et al., 2007	788	Modules are <u>autonomously</u> working units or elements that ensure a high interchangeability with little cost...		X								
Wiendahl et al., 2007	789	Flexible manufacturing systems... have <u>more</u> capacity and features <u>than normally used</u> ...	X									

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Wiendahl et al., 2007	792	...a mobile machine on wheels does not help much if the <u>supply media and power distribution</u> in the building is <u>restricted</u> [57].			x							
Wiendahl et al., 2007	794	...media distribution <u>covers all areas</u> of the factory via the ceiling and therefore imposes no restrictions... during relocation of equipment.			x							
Wiendahl et al., 2007	794	Each module is <u>autonomous</u> with regard to media and energy supply. The building can be expanded... without interruption of the production.			x							
Wiendahl et al., 2007	794	Universality... This enabler stipulates an <u>over-dimensioning</u> of objects to guarantee independence of function and use.	x									
Wiendahl et al., 2007	794	The <u>high grid width</u> supports the transformability in the building.		x								
Wiendahl et al., 2007	794	...the media distribution can be... a <u>grid</u> ... is hung from the ceiling and can be easily accessed by the workers themselves <u>at every location</u> ...			x							
Wiendahl et al., 2007	794	The module is mostly <u>self-contained</u> , transportable and has <u>standardized</u> interfaces. Therefore, it can be easily used in different locations...			x							
Wilkinson et al., 2009	49-50	...a determining factor... size (i.e. <u>smaller buildings were more marketable</u>)...				x						
Wilkinson, 2012a	159	...some plan shapes such as deep plan shapes were easier to adapt than others such as <u>irregular</u> shaped ones...				x						
Wilkinson, 2012a	160	...access to the building important during the building works as it affected builders' <u>access during the construction works</u> .						x				
Wilkinson, 2012a	162	...the vertical services cores are either <u>centrally located</u> within the floor plate or comprise <u>multiple locations</u> on the floor plate which facilitates a greater degree of flexibility in the <u>sub division</u> of the floor plates...			x							
Wilkinson, 2012a	163	The building occupies a <u>large</u> site... which makes it flexible for adaptation...	x									
Wilkinson, 2012a	163	The building... has <u>access to all four sides</u> of the building which makes it flexible for adaptation...						x				
Wilkinson, 2012b	401	Finally <u>aesthetics</u> was asserted to be important attribute in determining whether or not a building was adapted...									x	
Wilkinson, 2012b	401	...the <u>floor-to-floor height</u> affected the ability to reconfigure services installations.	x									
Wilkinson, 2012b	401	...where shapes such as deep plan were easier to adapt than others such as <u>irregular</u> shaped ones...				x						
Wilkinson, 2012b	404	...more <u>attractive</u> stock is retrofitted compared to less <u>attractive</u> buildings.									x	
Wilkinson, 2012b	404	...Buildings <u>without</u> a <u>mixed</u> land use undergo more frequent levels of retrofit possibly because less negotiation is required...			x							
Wilkinson, 2012b	405	... <u>attachment to other</u> buildings was important in determining the level of disruption to tenants of adjoining properties during retrofits...			x							
Wilkinson, 2012b	405	Access to the building was important in determining <u>the ease of delivery</u> of construction materials...						x				

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Wilkinson, 2014a	254	<u>Floor strength</u> determined possible land uses...	X									
Wilkinson, 2014a	254	A <u>central</u> [core] <u>location</u> gave greater scope for <u>sub-dividing</u> the floor plate...			X							
Wilkinson, 2014a	254	A central [core] location gave greater scope for... <u>minimised loss of net lettable area</u> .					X					
Wilkinson, 2014a	254	<u>Detached</u> buildings were easier and more desirable for adaptation and contractors worked faster with less user disruption...			X							
Wilkinson, 2014a	254	Access or the number of entry and exit points to buildings impacted on the <u>ease of adaptation</u> ...							X			
Wilkinson, 2014a	254	...and buildings with <u>unusual</u> floor plates or size were harder to adapt compared to open-plan space...					X					
Wilkinson, 2014a	254	Likewise, the... <u>distance between structural columns</u> , influenced the ease of adaptation for new uses (Arge, 2005).		X								
Wilkinson, 2014a	254-255	The technical grid and services equipment was important to evaluate whether the building could accommodate <u>extra capacity</u> ...	X									
Wilkinson, 2014a	255	With <u>single tenants</u> , when the lease expires owners can adapt... with <u>multiple tenants</u> ... the building may be partly empty... before owner's can adapt.			X							
Wilkinson, 2014a	256	...where buildings are <u>complex</u> , adaptation costs can surpass new construction...										X
Wilkinson, 2014a	259	...indicating that buildings having a poor appearance; such as a worn or <u>outdated form or look</u> are less likely to be adapted.					X					
Wilkinson, 2014a	259	...either <u>skeleton frame</u> or <u>load bearing</u> , has bearing on the flexibility and ease and the cost of building alterations.		X								
Wilkinson, 2014b	82	<u>Centrally located</u> services were most likely to be adapted, followed by <u>multiple locations</u> and 'other locations'...			X							
Wilkinson, 2014b	82	Narrow buildings were least likely to undergo adaptation whilst <u>medium</u> width property was most likely to be adapted.					X					
Wilkinson, 2014b	82	...site access... with buildings having access <u>on all sides</u> being most likely to be adapted.							X			
Wilkinson, 2014b	84	...with more <u>attractive</u> stock having a greater likelihood of adaptation.									X	
Wilkinson and Reed, 2011	727	...building accessibility was a critical success factor related to the <u>ease of the construction works</u> ...							X			
Wilkinson and Reed, 2011	731	...buildings with <u>large</u> floor plates were more likely to be adapted (0.59) than those with <u>smaller</u> floor plates...	X									
Wilkinson and Reed, 2011	732	Detached buildings are easier to adapt externally as owners <u>can get access to elevations</u> .							X			
Wilkinson and Reed, 2011	732	Internal adaptations are easier to carry out with <u>detached</u> ... buildings because owners can gain entry... <u>without disturbing or negotiating</u> with neighbours.			X							

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Wilkinson and Reed, 2011	733	There is a preference to adapt buildings <u>with smaller width</u> and these properties are either more versatile and or have greater flexibility...				x						
Wilkinson and Reed, 2011	734	Buildings with a front frontage of <u>50 metres or less</u> are more likely to undergo adaptation.				x						
Wilkinson and Reed, 2011	734	Buildings with services cores located <u>centrally</u> are more likely to be suitable for adaptation.		x								
Wilkinson and Reed, 2011	734	Buildings which are <u>less attached</u> to others are more likely to undergo alterations and extensions adaptation.		x								
Wong, 2010	175	...the given support elements define the <u>unalterable framework</u> around which one asserts control over the... arrangement of infill elements.	x									
Wong, 2010	175	...the <u>unalterable elements</u> ... must be composed and dimensioned <u>to allow for</u> adaptation to a wide variety of room/ space arrangements...	x									
Wong, 2010	177	...the main facade wall of the units is <u>not straight</u> ... This makes altering the internal layout of the unit difficult.		x								
Wong, 2010	177	<u>Despite</u> the <u>small</u> sizes of the rooms, the tenants demonstrated that a high number of use-territory configuration variations remain possible.	x									
Wong, 2010	178	Their [shear walls] <u>location</u> in the interior of the units <u>severely limits</u> the adaptability in terms of the arrangement of room-level elements.		x								
Wong, 2010	181	...to <u>shift all structural walls away</u> from the shared walls between habitable rooms... so that these walls can be taken away or moved...		x								
Wong, 2010	181-182	As a partition <u>wall can only be located at the solid wall</u> between bay windows, the expense of the bay <u>windows severely limited</u> the options for re-configuring the room layout for these units.		x								
Wong, 2010	182	...the more... <u>irregular</u> the form of the unitlevel shell the more difficult it is to configure the space into regularly shaped rooms ...		x								
Worthington, 2001	90	Making a building adaptable involves overcoming the tendency to <u>over-specify</u> design.				x						
Worthington, 2001	92	To him the ultimate adaptability was a set of spaces with <u>no name</u> that stimulated the user to propose a use.		x								
Worthington, 2001	92	His Unitarian church... provides a set of <u>varying dimensioned spaces</u> ...			x							
Worthington, 2001	92	His Unitarian church... provides a set of... spaces which are <u>exquisite in their ambience</u> and cry out to be used.									x	

Appendix 3.

Probability estimates.

Probability of insufficient privacy due to change 1:

A person's age or gender does not influence someone's need for privacy (Haans et al., 2007). However, introverts are more negatively affected by background noise than extraverts (Cassidy and MacDonald, 2007). Therefore, it is assumed that in 1 out of 5 times change 1 will result in insufficient privacy.

Probability of insufficient ergonomic comfort due to change 1:

In the UK, only 5% of the men are shorter than 1625mm, while the average height of a woman is 1610mm (Pheasant, 2003, p. 45). Thus, the average woman, in terms of height, is shorter than at least 95% of the male population. Furthermore, even the most optimal height for a workbench – specifically designed for the British male – will not be satisfactory for about 25% of males (Pheasant, 2003, p. 27, Fig. 2.7). Therefore, it is assumed that in 5 out of 8 times change 1 will result in insufficient ergonomic comfort.

Probability of insufficient thermal comfort due to change 1:

Perceived thermal comfort differs for people with a different gender (Karjalainen, 2012), age (van Hoof and Hensen, 2006) or ethnic background (e.g. Zhou et al., 2014). For example, there is evidence that older people, compared to younger people, prefer a temperature that is 2°C warmer (van Hoof and Hensen, 2006, p. 225). Therefore, it is assumed that in 1 out of 4 times change 1 will result in insufficient thermal comfort.

Probability of insufficient air quality due to change 1:

About 2 times more women than men experience symptoms related to indoor air problems (Reijula and Sundman-Digert, 2004, p. 35, Table 3). Furthermore, about 1,3 times more allergic people than non-allergic people are dissatisfied with a building's indoor air quality (Lundin, 1999, p. 99). Therefore, it is assumed that in 1 out of 10 times change 1 will result in insufficient air quality.

Probability of insufficient lighting conditions due to change 1:

In a study of Despenic et al. (2017, p. 100, Fig. 12), only about 13% of the occupants experienced conflict over the lighting settings with a significant frequency. Therefore, it is assumed that generally in 2 out of 15 times change 1 will result in insufficient lighting conditions. However, people with low vision, compared to people with normal vision, need greater lighting levels to reach their maximum visual performance (Haymes, 2006). In the UK, about 1,8% of working-age adults has a vision impairment (Department for Work and Pensions, 2018). Disabled people, of working age, in the UK on average are

37,5% less likely to have a job than non-disabled people (ONS, 2008, p. 14).

Therefore, it is assumed that in 9 out of 800 times change 1 will both (1) involve a person with low vision and (2) result in insufficient lighting conditions. Furthermore, it is assumed that in 5 out of 41 times change 1 will result in insufficient lighting conditions, without a person with low vision being involved. This distinction is useful because the severity in both situation is rated differently (0,2% and 0,02%).

Probability of insufficient operating space due to change 1:

A person in a wheelchair occupies more space and needs more space to manoeuvre than a person that is not in a wheelchair. In the UK, about 8% of working-age adults have a mobility impairment (Department for Work and Pensions, 2018), and about 2-3% of working-age adults uses special equipment to improve their mobility (Office for Disability Issues, 2011). Disabled people, of working age, in the UK on average are 37,5% less likely to have a job than non-disabled people (ONS, 2008, p. 14). Therefore, it is assumed that in 1 out of 64 times change 1 will result in insufficient operating space.

Probability of insufficient closeness due to change 1:

A person's gender does not influence someone's need for socializing (Haans et al., 2007). However, younger employees do experience a higher need for social interaction (Haans et al., 2007). Therefore, it is assumed that in 1 out of 5 times change 1 will result in insufficient closeness.

Probability of insufficient privacy due to change 2:

A person's work can require two types of privacy: (1) the privacy to be able to concentrate and work undisturbed; and (2) the privacy to be able to discuss sensitive issues without being overheard. Thus, a new job will likely require more privacy when it involves either more specialized work (thus, more concentration) or more managerial work (thus, more sensitive issues). In a study of West and Nicholson (1989, p. 340), about 54,5% of the respondents that reported a job change experienced an upward status move, about 36% of them experienced an lateral move, and about 9,5% of them experienced a downward status move. It is assumed that in about 1 out of 6 times a lateral move will result in greater privacy requirements. Furthermore, it is assumed that in about 1 out of 4 times an upward move will result in greater privacy requirements. Finally, it is assumed that a downward status move will not result in greater privacy requirements. Therefore, it is assumed that in 1 out of 5 times change 2 will result in

insufficient privacy.

Probability of insufficient ergonomic comfort due to change 2:

A different mixture of tasks with different relative duration of tasks causes different body dynamics during office chair use over the day. Therefore, workers with a different job have different ergonomic preferences in furniture (see Groenesteijn et al., 2012). Managerial workers differ most (about 20%) in terms of mixture of tasks from other types of workers (Brill et al., 2001, pp. 21-23). In a study of West and Nicholson (1989, p. 340), about 54,5% of the respondents that reported a job change experienced an upward status move. It is assumed that in about 1 out of 4 times an upward move will result in a significant change in mixture of tasks. Therefore, it is assumed that in 3 out of 22 times change 2 will result in insufficient ergonomic comfort.

Probability of insufficient thermal comfort due to change 2:

A person produces more heat when he or she is more physically active. However, in a study of Rowe (2001, p. 417), only 13% of reported switches, i.e. a switch from one office activity to another office activity that involves a different activity rate, resulted in a thermal sensation difference of 2,5 °C or more. Therefore, it is assumed that in 1 out of 8 times change 2 will result in insufficient thermal comfort.

Probability of insufficient air quality due to change 2:

A person produces more CO₂ when he or she is more physically active. For example, an employee who is on his or her feet working (see Rowe, 2001, p. 416) produces about 40% more CO₂ than a worker with an average activity rate (see Persily and de Jonge, 2017, p. 870). In a study of Rowe (2001, p. 417), only 13% of reported switches, i.e. a switch from an office activity to another office activity that involves a different activity rate, resulted in a thermal sensation difference of 2,5 °C or more. It is assumed that a similar percentage of switches will result in a significant difference in perceived air quality. Therefore, it is assumed that in 1 out of 8 times change 2 will result in insufficient air quality.

Probability of insufficient lighting conditions due to change 2:

When workers have a choice “...it is clear that office workers do not generally choose different illuminances for different tasks” (Boyce et al., 2006, p. 367). “The most likely explanation for this lack of effect of task type is that the range of visual difficulty experienced in everyday work is limited” (Boyce et al., 2006, p. 367). Therefore, it is

assumed that in 1 out of 100 times change 2 will result in insufficient lighting conditions.

Probability of insufficient operating space due to change 2:

A worker's position in the company's hierarchical structure affects the amount of space that will be reserved for him or her (Hakfoort and Lie, 1996, pp. 189-190; Neufert and Neufert, 2000, p. 346). The main functional reason why a managerial employee's workstation needs more space, than a non-managerial employee's workstation, is so that he or she can formally receive visitors at his or her workspace. This additional space requirement can add about 60% of extra space to the workstation (de Chiara et al., 1992, pp. 225-226).

Furthermore, in different fields of work, different space requirements per worker are common (Miller, 2014, p. 163, Fig. 4). Besides the need to formally receive visitors at the workstation, the only other functional reason why one person's workstation needs more space, than another person's workstation, is additional storage requirements. A larger desk or working area does not fulfil any additional functional purpose, since a person's "*normal working area*" is limited by the size of his or her arms (Pheasant, 2003, pp. 55-56).

In a study of West and Nicholson (1989, p. 340), about 54,5% of the respondents that reported a job change experienced an upward status move, about 36% of them experienced an lateral move, and about 9,5% of them experienced a downward status move. It is assumed that in about 1 out of 6 times a lateral move will result in greater space requirements. Furthermore, it is assumed that in about 1 out of 4 times an upward move will result in greater space requirements. Finally, it is assumed that a downward status move will not result in greater space requirements. Therefore, it is assumed that in about 1 out of 5 times change 2 will result in insufficient operating space.

Probability of insufficient closeness due to change 2:

Social interaction between co-workers has been said to: (1) facilitate the sharing of knowledge (Chen and Huang, 2007); (2) reduce work-related stress (Hagihara et al., 1998); and (3) help prevent a person from becoming bored of straightforward and repetitive work that does not require a lot of his or her attention (Fisher, 1998). These three effects are mostly associated with a lateral (more knowledge based work), upwards (more stressful work) and downwards move (more repetitive work), respectively. In a study of West and Nicholson (1989, p. 340), about 54,5% of the respondents that reported a job change experienced an upward status move, about 36% of them experienced an lateral move, and about 9,5% of them experienced a downward status

move. It is assumed that in 1 out of 4 times a lateral move will result in greater closeness requirements. Furthermore, it is assumed that in 1 out of 5 times an upward move will result in greater closeness requirements. Finally, it is assumed that in 1 out of 8 times a downward status move will result in greater closeness requirements. Therefore, it is assumed that in 2 out of 9 times change 2 will result in insufficient closeness.