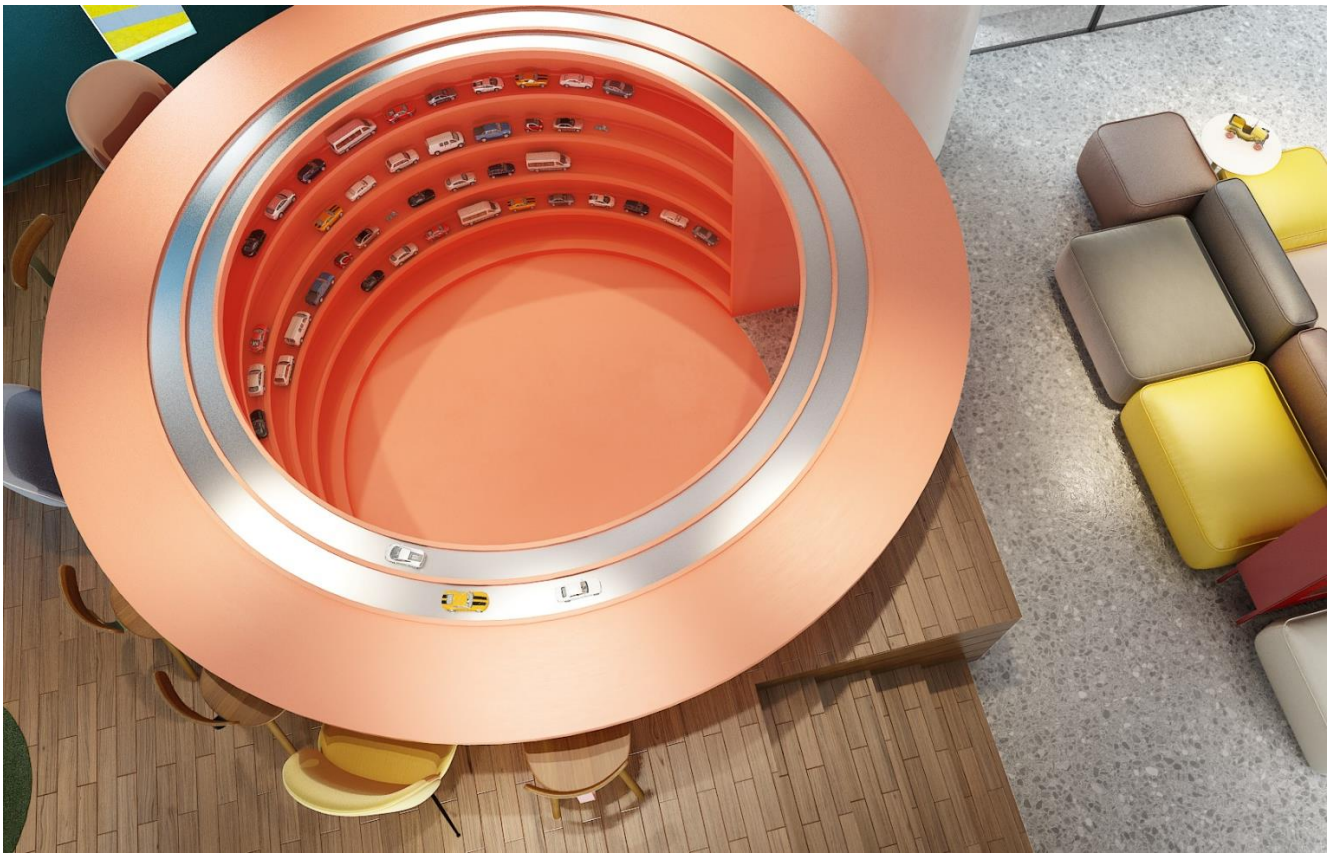
PRODUCT-SERVICE-SYSTEM, A STRATEGY FOR CREM TO MINIMIZE MATERIAL LEAKAGE IN THE OFFICE (TRANSFORMATION)

A study of minimizing material leakage within CRE by using PSS



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Motivation in research

Before I started the MBE course, I spent around two years working as an architect and interior designer in Thailand. Almost 20 projects of office renovation were done there. I found that most of the major companies or organizations prefer building or renovating their office entirely new to fit with their organizational paradigm.

After the rental contracts are expiring and they moved out, most of the building material and services there are disposed of which become construction waste (some part of the building product is difficult to reuse as it is tailor-made). Doing that leads to unsustainable construction. Furthermore, some companies might have to pay extra expenditure to dispose of those materials after moving out. Also, the companies might need to pay a huge amount of capital for building headquarter office all over again once they relocate or build their new office I see this is inefficient in both environmental and economical aspects. Once I am aware of the unsustainable issue there, I wish to study more deeply to find a solution or strategy that could mitigate the current unsustainable problem that occurs in office transformation.

Abstract

The world is moving toward environmental sustainability and a circular economy. The construction industry generates more than one-third of waste in landfills around the world is considered a critical sector. Material leakage is becoming one of the most concerning issues in the construction industry globally.

Due to globalization, many corporations are growing in size, as a result, there are numerous corporate real estate (CRE) changes. These changes in the corporate real estate sector lead to a significant amount of material leakage generation which could cause negative effects on company stakeholders as well as the environment. Many researchers claim that office refurbishment is the main material leakage contributor, hence the company should apply a circular strategy to minimize the material leakage effects

A product-service system (PSS) is a procurement strategy that provides a combination of products and services to meet consumers' demands. Most of the PSS product ownership remains with the PSS providers while consumers can access or possess products in other ways such as leasing or subscribing instead of traditional purchasing. By doing so, the PSS providers take more responsibility for the products, and the products are treated more effectively and properly by the PSS providers because they have specialized facilities and knowledge to support product treatment. This will also lead to a reduction in material leakage. In sum, the PSS strategy could directly contribute to the circular economy and it seems to be a proactive solution to minimize material leakage in office refurbishment.

According to a built-up story, the main research question is formulated, which is "*To what extent does the Product-Service system (PSS) help corporate real estate (CRE) in minimizing material leakage?"*

To assert that implementing PSS could minimize material leakage in CRE, theoretical research, empirical research, and the analysis of both theoretical and empirical research findings have to be conducted. The theoretical research is to identify all research-related concepts and the relationship between each concept, namely PSS, material leakage, and CRE. Also, the potential of PSS in minimizing material leakage is studied while the theoretical research is conducted by literature review.

The empirical research investigates how and to what extent can PSS contributes to material leakage minimization in real-life practice. This is will be conducted by a case study.

Thereafter, an analysis of the theoretical and empirical research findings is conducted to find whether both of them are aligned before using the result to answer the research questions.

The result of the research shows that material leakage minimization seems to be a consequence of PSS implementation. The circularity of the PSS product is greater compared to a similar product that is provided by a linear economy strategy (take-make-dispose). However, material leakage minimization is not yet a primary factor for consumers (CRE) to use PSS.

Keywords: Product-Service-System, material leakage, corporate real estate management, office refurbishment, circular economy

Preface

This report marks the completion of the Master of Science in Management in the Built Environment at the Delft University of Technology. The research “Product-service system, a strategy for CREM to minimize office refurbishment material leakage” contributes to the answer to my curiosity when I worked as an architect. I always want to find a proactive solution to minimize material leakage in office refurbishment.

Throughout the year, a number of people have greatly contributed to my thesis. I would like to express my sincere gratitude to my mentors, Herman Vande Putte and Tillmann Klein for your kind providing valuable feedback and support that help me overcome hindrances in conducting research. I would like to extend my gratitude to Tuuli Jylhä and Juan Azcárate-Aguerre for your guidance during the first part of my thesis.

The research could not have been complete without the participating interviewees. I would like to extend my gratitude to all of them for scarifying their valuable time and for giving me precious information.

Lastly, I would like to thank all of my lovely family and friend who always support me during this time.

Thanon S

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Terminology, terms' meaning in different contexts, and abbreviations:

Terms	Abbreviation	Meaning of the terminology in a different context
Circular Economy	CE	
Construction & Demolition waste	C&D waste	
Corporate real estate	CRE	
Corporate real estate management	CREM	
End-of-life management	EOL management	
Furniture as a service	FAAS	
Product-service systems	PSS	For PSS provider: PSS = business strategy For Consumer: PSS = procurement Overview: PSS = product/ service delivery model
Research and development	R&D	
Renovation & Retrofit waste	R&R waste	
Waste Electrical and Electronic Equipment	WEEE	

CHAPTER 1:

Introduction

1. Introduction

1.1 Background

Due to globalization, many corporations are growing in size as a result there are numerous corporate real estate (CRE) changes.

According to Haynes et al (2017a), the workplace or office is one of the important elements in CRE, which needed to be aligned with the other CRE elements such as the corporations' paradigm, place, process, or people. Once the corporations create their workplaces, micro decision-making factors such as the specification and layout of the office need to be aligned with the other organizational elements. Therefore, most corporations prefer building or renovating their office entirely new to best align with their other organizational paradigm.

Once the office refurbishes, most of the existing office construction elements and equipment are often left as waste and taken to a landfill or incinerated. Meanwhile, new headquarters are often built from mostly new materials. By doing this, the inefficient office transformation by having enormous material leakage cause negative effects on both environmental and economic aspects.

More environmental pressure has been produced by office construction waste and equipment waste. Nowadays, there are more than 5 tons of waste are generated for every 100 sq.m. floor area of a fit-out project which is considered double compared to a typical commercial building construction project with the same floor area (Hardie et al, 2011). "The average rate of waste generation is reported to be 6.4t per 100 m2 of gross internal floor area (GFA) for offices (based on four UK office fit-out projects), 10.3t per 100 m2 of GFA for retail (based on six projects), and 33.7t per 100 m2 of GFA for education institution buildings (based on two projects). " Casas-Arredondo et al (2018)

Furthermore, the more waste is generated, the more cost that organization needs to pay and the residual elements might lose their opportunity to be utilized for their second life. Also, once the office is refurbished, the companies might need to pay a huge amount of capital for building their new headquarter all over again.

Corporate real estate management (CREM) is accounted for the second-largest expenditure in almost every organization after personnel, office planning and construction costs accounted for 20% of the real estate-related cost (Verhoeff, 2014 and Deloitte, n.d.). Also, the number of office refurbishments is rising consecutively every year (Clark, 2021). The changes in the office call for a more circular strategy to optimize the process and reduce material leakage.

To cope with material leakage during an office refurbishment, a Product-service system (PSS) could be a promising strategy. A product-service system (PSS) is a newly emerged procurement strategy that could directly contribute to a circular economy. PSS provides integrated products and services to meet consumer demands. Most of the provided PSS product ownership remains with PSS providers, while consumers only pay for the product's functionality (Tukker, 2004). Since the ownership of the product remains at the PSS providers, products are treated efficiently throughout their entire life cycle (including after their end-of-life). Also, a PSS consumer could benefit from the product ownership that remains to the PSS provider by using the product with less or without the product's responsibility. Material leakage from using PSS products by a consumer is minimized.

As a result, there might be less material leakage by using PSS. In addition, in using PSS, consumers can pay a less initial cost for accessing products' functionality by spending an operating expense instead of capital expenditure, while products maintenance, repair, and upgrade are already included.

1.2 Problem statement

Due to the office booming phenomenon, more frequently taking place in office refurbishment (compared to other construction projects), and a relatively higher amount of waste generation during office refurbishment projects, corporate real estate is considered a major construction material leakage contribution.

PSS is a newly emerged procurement strategy that has the potential to mitigate the issue. However, There have been only a few successes PSS cases in the corporate real estate and construction industry in the market nowadays. Therefore, many consumers have been still afraid of uncertainty in using PSS in this context.

This research aims to provide clarified information on what potentials and how PSS could help the office in minimizing material leakage and provide additional benefits. By doing so, the researcher hopes PSS could be considered as another alternative strategy to cope with the material leakage issue within CRE.

1.3 Research aims and objectives

This research has three main objectives, first is to understand the current situation of the material leakage problem in office refurbishment and the potential of PSS in mitigating this issue.

Second, to understand to what extent and how the PSS contributes to material leakage minimization in real-life practice. Does the PSS implementation in real-life practice go in accordance with the theory, what is the difference and similarity, and what is the logic behind the difference and similarity?

Lastly, this research is to demonstrate how PSS benefits office/ CREM. And is it worth applying PSS to the CRE regarding material leakage minimization wise?

1.4 Scientific and societal relevance

1.4.1 Scientific relevance

Nowadays, the office booming phenomenon results in a higher amount of material leakage during an office refurbishment, which contributes to various negative effects on the project-related stakeholders and environment.

PSS is a promising strategy that has the potential to cope with this issue. However, the specific scientific literature on minimizing material leakage by applying PSS is still limited. Therefore, the clarification on how PSS could help the consumer (CRE), PSS provider, and other related professionals regarding minimizing material leakage and the benefit of using PSS still has to be clarified.

1.4.2 Societal relevance

The PSS has already proven its success in other sectors, such as Netflix, Spotify, or fitness and health club subscriptions. However, in the built environment and construction industry there is a rare successful case of PSS in practice. One of the research objectives is to promote using PSS in the built environment industry since PSS could evolve how corporate real estate portfolios access the product functionality in many ways. Also, it could optimize CRE resource utilization and lessen environmental impact.

Moreover, the material leakage issue during an office refurbishment might be improved once the potential of minimizing material leakage of PSS implementation is revealed. This could provide another interesting alternative strategy for CREM toward environmental sustainability.

1.5 Research questions

According to the introduction, office transformation (refurbishment, relocation, renovation, etc) could generate a huge amount of material leakage which affects both environment and the economical aspect of the corporation itself. PSS is a procurement strategy that seems to be a promising strategy to minimize material leakage as the product is treated properly by the PSS provider throughout its life cycle. Furthermore, since most of the product ownership remains at a PSS provider, a consumer could use the product without (or with less) product responsibility. Therefore material leakage from using the PSS product of consumers could be reduced accordingly.

Based on the above paragraph this hypothesis is established. “To minimize material leakage in the CRE (especially an office refurbishment), using a Product-service system (PSS) could be a promising strategy”

According to this hypothesis and a built-up story, the main research questions are formulated.

Main research question: **“*To what extent does the Product-Service system (PSS) help corporate real estate (CRE) in minimizing material leakage?***

To answer the main research question, four sub-research questions have to be answered.

1. ***What is the Product-service system (PSS)? And what is the potential of PSS to minimize material leakage in office refurbishment?***

2. ***In real practice, to what extent is material leakage minimized by the product-service system?***

3. ***What are the benefits of a Product-service system (PSS) to the consumers and PSS providers?***

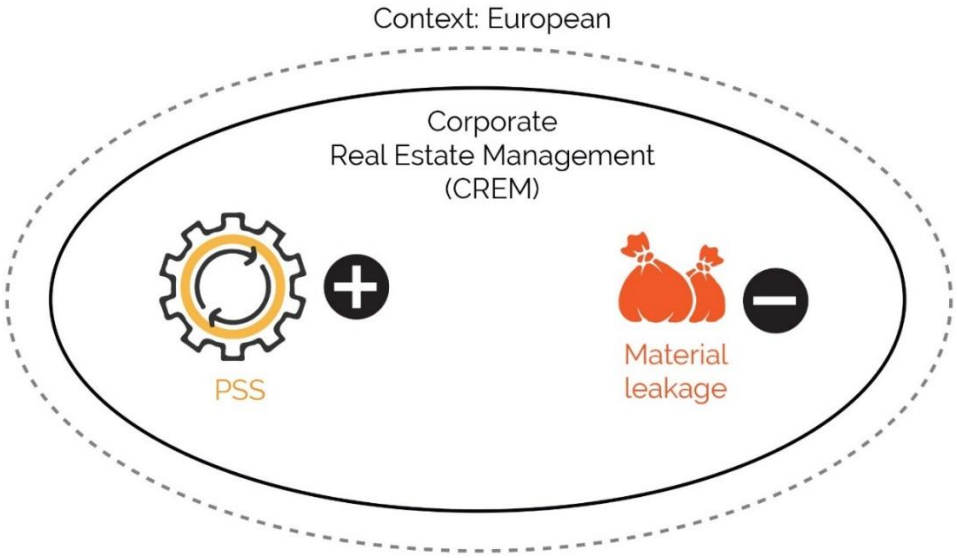

Figure 01: Research conceptual model (own illustration)

1.6 Research methodology

The research is structured into 3 sections, namely theoretical research (literature review), empirical research (case study), and analysis and conclusion.

1.6.1 Theoretical research

Theoretical research is to provide the theoretical background of the research-related aspects. In this section, the information regarding the concept of Corporate Real Estate Management (CREM), Office refurbishment, Product-Service Systems (PSS), and material leakage are explored through a literature review to generate a broad theoretical framework. The output of theoretical research is frameworks that explain the proposition of how PSS could improve material leakage minimization within CRE and how PSS could provide possible benefits to the CRE as a consumer that applies PSS. The theoretical research content is presented in chapter 2.

All the literature review in the theoretical research is developed through studying and analyzing scientific papers, journal articles, reports, and books. The main source of data is an online database namely, Scopus, Google scholar, and the TU Delft repository.

1.6.2 Empirical research

Empirical research is conducted through case studies of PSS providers, PSS consumers (CREM), and other PSS-related professionals. The objective of conducting empirical research is to study how PSS is provided by the PSS providers, how it contributes to material leakage minimization in real-life practice, and does the findings of the theoretical research are in line with real practice.

In-depth interviews and case-related literature reviews are the main investigation methods of case study data collection. The outcome of the empirical research is developed from a combination of different PSS-related stakeholders (information from different parties). Furthermore, The developed frameworks from theoretical research are used as a basis of the empirical research investigation to bridge the gap between literature and practice for demonstrating an actual phenomenon of applying PSS to the office.

In the empirical research, the PSS providers' cases are mainly focused on as they can provide comprehensive information on the entire life-cycle of PSS regarding the provided PSS and material leakage-related aspects. PSS consumers and other PSS-related professionals are also investigated to explore different perceptions of using PSS and PSS-related information regarding material leakage minimization.

In this research, multiple case studies with the holistic analysis case design of Yin (2002) are applied. This case study design allows a researcher to investigate the overview of PSS and office phenomena in the current practical context. The content of empirical research is presented in chapters 3 and 4.

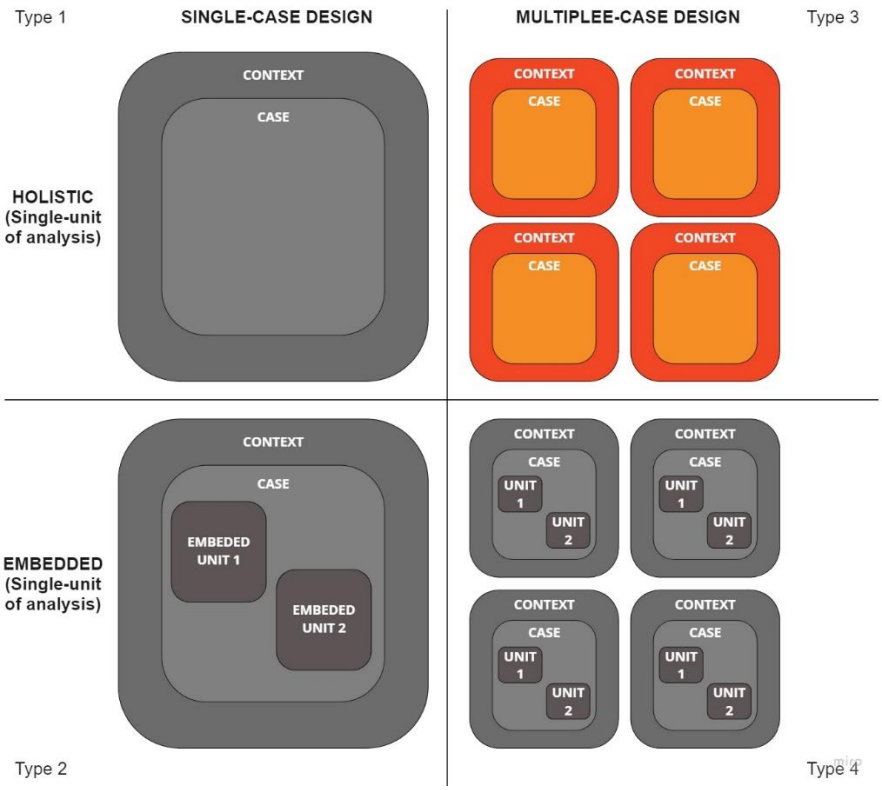

Figure 02: Case study design (based on Yin, 2002)

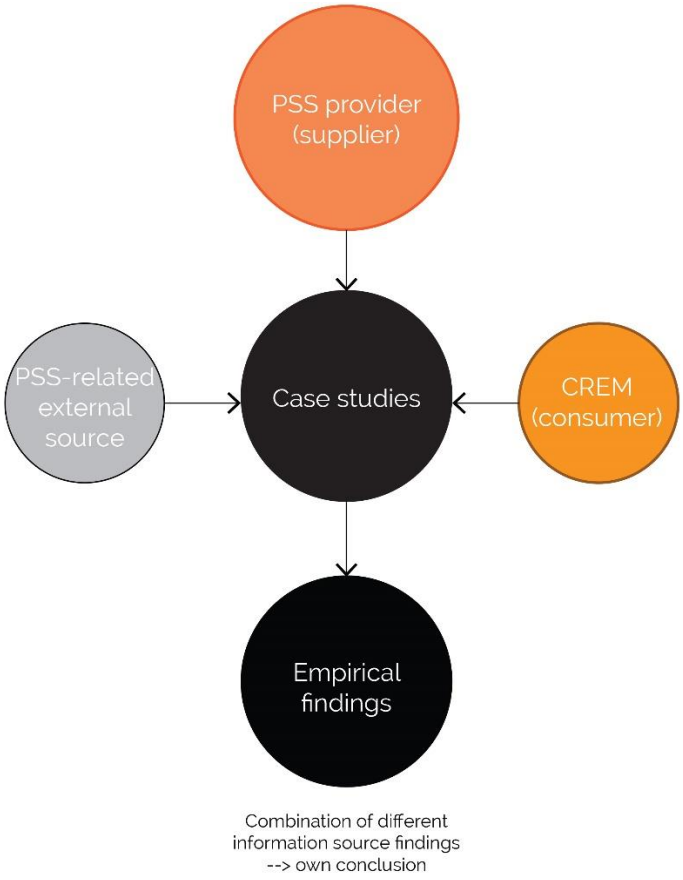

Figure 03: Stakeholders address in the cases study (own illustration)

1.6.3 Analysis and conclusion

The last phase aims to identify the similarity and differences between the empirical and theoretical research findings, and the logic behind the similarity and differences regarding the researched aspects. These are synthesized in this phase before being concluded as answers to the research questions. The analysis and conclusion are presented in chapter 5. Figure 04 illustrates the overview of the research design and procedure.

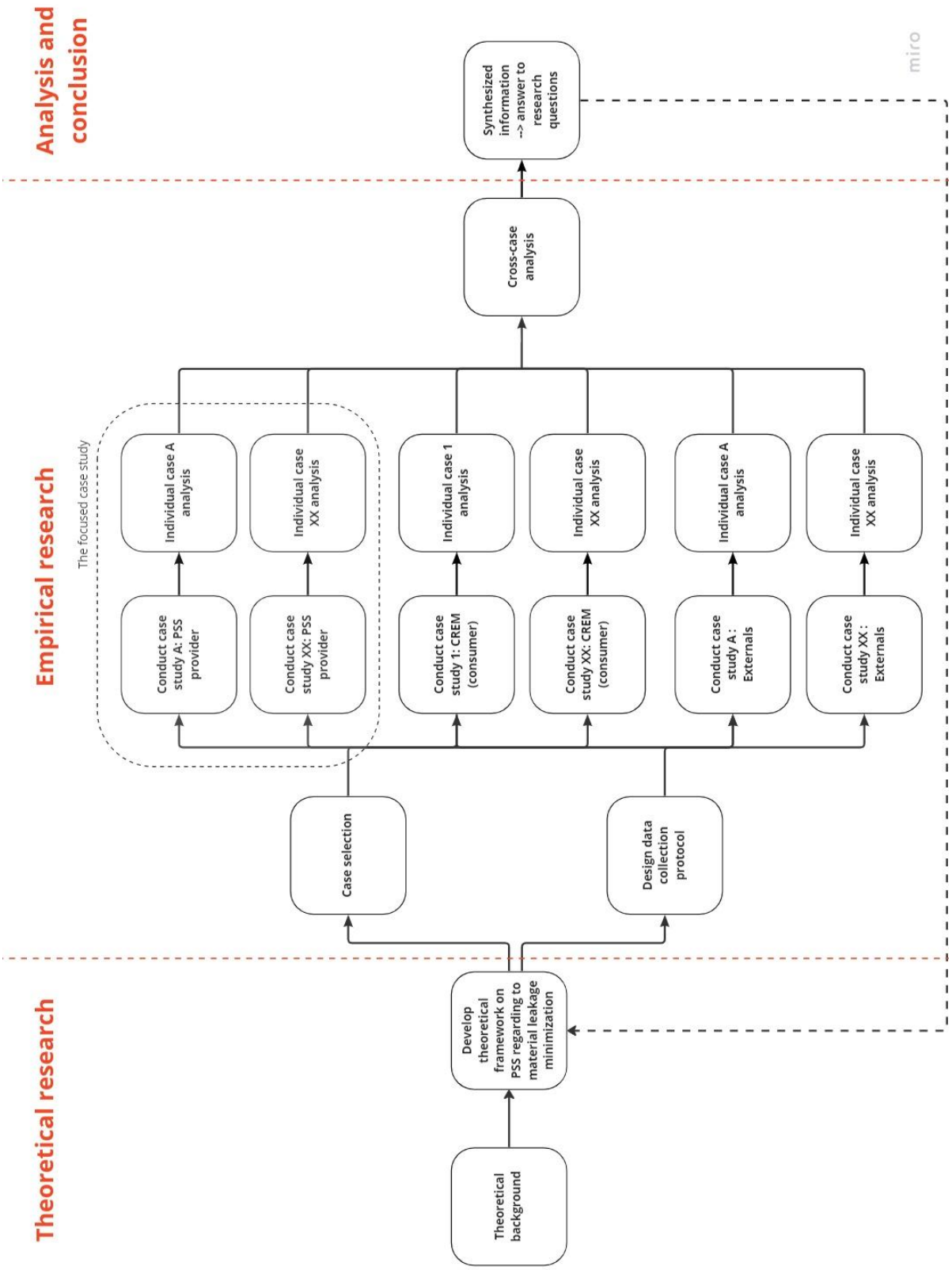

Figure 04: an overview of the research design and procedure (own illustration)

1.7 Research output

The research aims to deliver the following outputs:

Objectives	**Deliverable**
Understand the global situation and consequence of material leakage during an inefficient office refurbishment	Theoretical information (qualitative information): 1. what are the drawbacks caused by material leakage 2. What is the material leakage in the office (refurbishment) and what factors contribute to it?
Understand the correlation between PSS and material leakage minimization	Theoretical information (qualitative information): What potential of PSS could lead to material leakage minimization and how it works?
Investigate successful PSS cases on how and to what extent PSS can minimize material leakage in the office	Theoretical and case study information (qualitative and quantitative information): To what extent and how PSS could minimize material leakage throughout its life cycle?
Affirm whether applying PSS to CRE could minimize material leakage and provide other benefits to the CRE	Clarification on why PSS could be considered to be applied in corporate real estate (if PSS shows the potential in minimizing material leakage).

Table 01: Research objective and the deliverable (own illustration)

1.8 Dissemination and audiences

The primary audience of the research is CRE managers who are a decision-maker in corporate real estate management, PSS providers, and other construction-related professionals.

Due to the movement toward environmental sustainability is highly concern in the corporate real estate and construction industry these days, material leakage minimization which contributes to environmental pressure reduction is an essential aspect.

Since the PSS has the potential for contributing to material leakage minimization, raising the awareness of minimizing material leakage by using PSS in CRE to the aforementioned professionals is crucial. This could provide them with an alternative option in CRE and construction management toward environmental impact reduction.

CHAPTER 2:

SUMMARY OF THEORETICAL RESEARCH

2. Summary of theoretical research

In this chapter, all the research-related concepts, which include CRE (office) and office refurbishment, material leakage, and product-service system (PSS), and their correlation between concepts are elaborated as a theoretical background of this research(see figure 05). Data gathering for the theoretical research is conducted by literature, scientific articles, and document review.

Subsequently, this theoretical information is used to formulate the framework which is used as a basis of empirical research investigation.

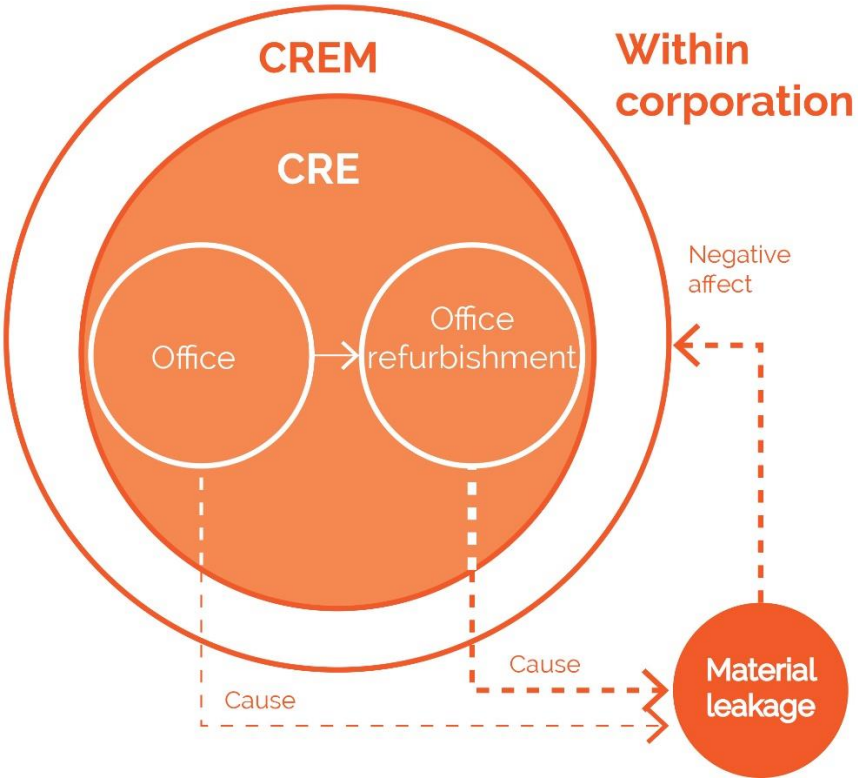

Figure 05: Research conceptual relationship diagram (own illustration)

2.1 Corporate real estate (CRE) and Corporate real estate management (CREM)

The term “corporation” refers to any medium or large organization which includes private, public, or non-profit organizations (Kooymans, 2000).

Corporate Real Estate (CRE) refers to the real estate occupied by the (non-real estate) corporate, it is a physical entity to facilitate and contributes the corporate activities to achieve its primary goals (Kooymans, 2000 and Widarta, 2021). CRE touches all layers of the corporate physical entities of Brand’s (1994) shearing layer which includes property site, building, interior space, and facilities.

Real estate is considered one of the highest investment businesses among others (Widarta, 2021). Also, in most corporate, real estate is accounted for the second-largest expenditure after personnel (Verhoeff, 2014).

Corporate Real Estate Management (CREM) refers to the management wise of the CRE which aims to best facilitate corporate operations. One effective approach to optimize the corporation's performance is to align the CRE strategy with the organizational strategy that contributes to the corporate primary business goals (Haynes, 2017b).

Originally, the CRE manager mainly focused on providing a physical place for corporate operations. This century, after the development of CRE, the role of CREM has improved to not only creating a workplace and searching for a suitable location for a company but also contributing to many other CRE-related aspects such as organization productivity through workplace solution devising, organization internal culture development, and disposal, throughout the properties life cycle which could best contribute to the organization goals (Omar and Heywood, 2014).

2.2 Office and office refurbishment

According to Haynes et al (2012), Office or (work) place is one of the CREM strategic elements (10Ps) that need to be aligned with other CREM strategic elements and organizational strategies. By doing an alignment strategy, it could optimize the corporate toward its primary goal.

As reported by Haynes et al (2017), the office environment is considered a key contribution to knowledge creation and transfer within the organization. In other words, the workplace could directly contribute to organizational performance improvement as it could influence employee productivity. An office can lure and retain top talents by creating an attractive and well-facilitated working environment (Kemperman and Appel-Meulenbroek, 2019).

Shaping an office is an essential step, both macro decision-making factors and micro decision-making factors are taken into account to ensure organizational demand compliance. Macro decision-making factors refer to location aspects of the head office, such as which country, or city should the head office be best located, while micro decision-making factors are office-related aspects, such as office specification, office environment, or layout (Haynes et al, 2012).

Office refurbishment is usually taken place once some changes in CRE are required. These have to comply with CREM strategic alignment, for example, one company is growing which results in more employees being needed, therefore more office space is required.

Deloitte (n.d.) reported that Office planning and construction costs accounted for 20% of the corporate real estate-related cost which is a relatively high expenditure since CRE is the second-highest cost in most organizations after personnel. Moreover, Hardie et al (2011), mentioned that office refurbishment generates a relatively high amount of construction waste these days.

2.3 Material leakage during an office refurbishment

According to Ghaffa et al (2020), the construction industry has generated a huge amount of waste which is more than one-third of waste to landfills around the world. Moreover, the construction industry is also one of the largest CO2 emissions from energy consumption, which accounted for 38% of total CO2 emission-related global energy (Tann, 2021). Eurostat (2020) reported that construction and demolition waste (C&D) in the EU-27 accounts for 35.7 tons a year. Unfortunately, only 20-30% of C&W waste is reused and recycled collectively (Fard Fini and Forsythe, 2020).

Material leakage during office refurbishment is mainly Renovation and Retrofit waste (R&R waste), which is generally mixed between C&D waste and equipment/ appliances waste (Yu et al., 2021). The majority of R&R waste, 83%, is ended in landfills (Yu et al., 2021). Four main interrelated factors namely, time, cost, transportation distance, and contamination of material, highly influence the R&R waste recovery rate (Fard Fini and Forsythe, 2020). The typical office refurbishment waste and which type of office refurbishment waste that usually ends up in landfill could be seen in Appendix C.

Even though a circular economy approach such as a closed loop of material, cradle-to-cradle has been introduced to minimize material leakage, R&R waste is still considered relatively less amount waste recovery rate. The first major barriers that minimize R&R waste recovery are the design/ feature of the product itself which is not aimed to be disassembled, reused, or recycled after its end of life. Therefore, at the end of its life, it is considered composite/ mixed waste which is more difficult and more expensive to process before being reused or recycled (Yu et al, 2021; Fard Fini and Forsythe, 2020).

The operation process of recycling and reusing strip-out products from the construction site has to deal with many challenges (Fard Fini and Forsythe, 2020). Once products are decided to be reused or recycled during or before office refurbishment, selective demolition is required to maintain the value of the material after demolition (Yu et al, 2021; Fard Fini and Forsythe, 2020). Selective demolition is a delicate time-consuming and costly process that costs 20-25% higher compared to traditional demolitions (Yu et al., 2021).

Selective demolition consists of three main phases which are ordered by components' movability (the components that are easier to be removed are stripped out first). The first phase is a remaining and non-fixture removal which includes electrical appliances and furniture (stand-alone objects). In the second phase, stripping out the components (building/ space attached components), such as doors, windows, kitchen, toilet fitting, A/C system, pipes, and cable/ wire, only the structure or building shell remains. The last phase is to demolish the remaining element (structure) such as an internal brick wall, finishing components, and concrete structure (Yu et al., 2021).

During selective demolition, which is considered a time-consuming and costly process, various challenges which could hinder material recycling and reusing arise. Damage to the striped-out material usually occurs during removal and transporting to the recycle manufacturer, this results in reducing the reuse/ recycle value of the material (Fard Fini and Forsythe, 2020). Sometimes, problems during the material or component transportation to a recycling manufacturer arise, such as the component might not fit in the service truck or service elevator. Therefore it has to be cut into small pieces which could also reduce its material value (Fard Fini and Forsythe, 2020). These often cause extra costs and time for extra procedures. Meanwhile, the knock-down or modular product could avoid these challenges proposed by some circular-oriented suppliers.

Due to high uncertainties (challenges) between the stripping out and the recycling process, at the end of the recycling process, the recycling benefit might be not worth it. Property owners and corporations are responsible for the management of R&R waste, they usually tend to choose the easiest way that best optimizes their time and cost (Fard Fini and Forsythe, 2020). General contractors (not demolition specialized contractors) are usually hired by owners to deal with the office R&R waste. Since the general contractors are not demolition specialists, they are always induced by the owner's brief which inclines toward the easiest way that best optimizes cost and time (Fard Fini and Forsythe, 2020). Therefore, most R&R is usually ended at landfills without any recycling process. According to the research of Fard Fini and Forsythe (2020), the contractor disposes 65-80% of R&R waste to landfills. The typology of R&R waste in office refurbishment is elaborated in Appendix B.

Office refurbishment which has a waste recovery rate lower than 50% is considered unsustainable and a material leakage contributor. It needs to be improved to comply with the European circular economy plan, which aims to reduce total waste generation and use of primary resources by half by 2030 (European Commission, n.d.).

2.3 Why office refurbishment is considered a material leakage contribution

Office refurbishment is generating a huge amount of material leakage and tends to increase in the upcoming years due to the following reasons namely, office booming phenomenal, office refurbishment usually takes place more frequently than other commercial construction projects, and it generates a relatively higher amount of R&R waste compare to the other construction/ renovation projects.

2.3.1 Office construction/ renovation is booming as well as office refurbishment usually takes place more frequently than other commercial construction projects.

The number of offices is rising these days, more than 20 million sq.m. of office or workplace was leased globally just before the Covid-19 crisis (JLL, 2021). Even though it slightly dropped from 2020 to mid-2021, the office sector is rebounding with the increase in Covid-19 immunity and vaccination. Based on Clark (2021), construction starts rose around 20% from October 2020 to March 2021 compared to the previous half-year in the UK, this has been the highest project completion volume by Deloitte in the last 18 years. More than half of those project completion was a renovation of existing office stock. Also, the Covid-19 pandemic is considered an office renovation catalyst, as many existing offices are turning into Covid-19 proof to comply with a new normal working pattern (Clark, 2021).

Meanwhile, in the Netherlands, there are around 100,000 office buildings operating (Statista research department, 2021). Simultaneously, as reported by Jensen et al (2019), the number of office transformations and demolition has been increasing substantially. In 2016 more than 1 million sq.m. office building was transformed while around 250,000 sq.m. was demolished in The Netherlands (see figure 06). Typical commercial buildings usually require refurbishment every 20-25 years, while office refurbishment or fit-out (interior renovation, a process of removing and installing interior components which include floors, walls, windows, furniture, and M&E service) occurred more frequently, they usually take place every 3-10years, (Casas-Arredondo, 2021; Hardie et al, 2011).

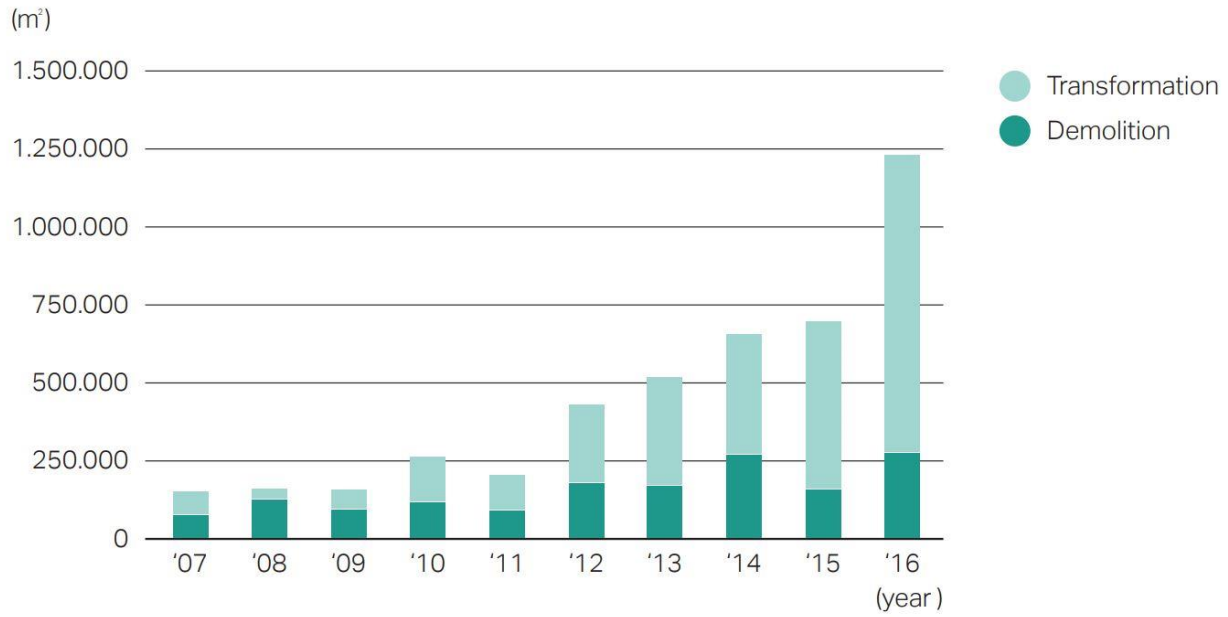

Figure 06: The rising number of office transformations and demolition in the Netherlands, source: Jensen et al (2019)

2.3.2 Office refurbishment generates a relatively tremendous amount of C&D and R&R waste (material leakage)

Due to a great number of office refurbishments, huge construction waste could be generated accordingly. As stated in the report of BPP (n.d.), more than 5 tons of waste is generated for every 100 sq.m. floor area of a fit-out project. This amount of waste generated for renovation is double compared to a typical commercial building construction project with the same floor area, considering that the commercial construction average waste generated is 3.9 pounds per sq. feet. of building area (equal to 2.09896253 tons/ 100 m2) (Hardie et al, 2011; Freymann et al, 2018).

Additionally, apart from construction waste, the fit-out office project could also produce massive office equipment waste each year. United States EPA estimates that there are 8.5 million tons of office assets are disposed of in the US landfills every year, it is worth around 23 million US dollars, although some of them are still functioning and there is a possibility to reuse or rematerialize (Bertoli, 2017). Meanwhile, in European countries, the increase in office equipment replacement is contributing to the growth of landfill space demand in Europe (Besch, 2004). In Germany, approximately 700,000 tons of office furniture are disposed of annually, most of which end up in landfills (Besch, 2004).

Moreover, once more construction waste and office asset waste are produced inefficiently during the office transformations and demolition, the amount of waste management cost that organizations increase consequently. As reported by Bertoli (2017), the average waste management cost is at least 4% of the total organization's expenses.

Remony (2018) stated that the existing built environment will be comprised 87% of the total built environment in 2050. The number of office demolition and renovation is rising and it usually takes place more frequently compared to other construction projects. As a result, more material leakage will be generated in the coming year. A transition toward environmental sustainability and circularity in office refurbishments or demolitions has to take place as soon as possible

2.4 Why material leakage minimization is essential for CREM.

One cannot deny that CRE is called for the material leakage minimization method since it not only reduces the environmental negative effect such as CO2 emission and material scarcity but it also brings about various benefits to the corporate such as financial optimization or corporate competitive advantages by achieving environmental sustainability.

Nowadays, environmental sustainability is one of the main criteria for CREM as there are environmental-related regulations or agreements such as the Paris agreement or the European Circular Green Deal which need to comply with. Besides, the higher environmental sustainability level company could result in higher corporate real estate value, for example, investors or prospective tenants are willing to pay more for a LEEDS-certificated building (WM, n.d.). In addition, It is easier for an environmentally sustainable real estate to get a loan or mortgage from a bank in Europe these days (P,B, personal communication, 2022).

Moreover, once the material leakage is reduced, real estate operational expenditure is decreased due to the reduction of property carbon footprint, energy consumption, and disposal fee (WM, n.d.). This allows the corporate to allocate this capital to the primary business of the corporate.

2.5 Product-Service system, a new procurement strategy

Product-Service-System (PSS) is a business strategy that emerged in 1999, to provide integrated products and services to meet consumer demands. In most provided PSS, a product’s ownership remains with PSs providers, while consumers only pay for products’ functionality. Since most of PSS providers are responsible for monitoring the entire life cycle of the product (including after the end of the product life cycle), products are used and treated more efficiently which could result in more product sustainability (Wetsteijn, 2021). In addition, by applying PSS, the consumer will be incentive from the maximum lifespan product with less maintenance cost and avoid paying disposal fees when the products reach the end of their life cycle. According to Wetsteijn’s (2021) and Baines et al (2007) report, international institutions namely the UN and EU see PSS as a high-potential strategy toward a circular economy, it could provide various benefits to consumers, PSS providers, and the environment.

A common example of PSS is a “Pay-per-lux” model by Phillips. This changes how consumers procure lighting equipment and systems. Instead of buying lighting equipment such as light bulbs, electrical wires, breaker boxes, etc., Phillips provided consumers with complete products and services, including a maintenance and repair service, but all of the lighting equipment ownership remain at Phillips. The consumers only pay Phillips a monthly or annual fee calculated by the amount of the illuminance unit (Lux).

Originally, PSS could be formed by either product-oriented companies providing additional services or service-oriented companies providing a product to fulfill consumers’ demand (Baines et al, 2005) (see figure 07).

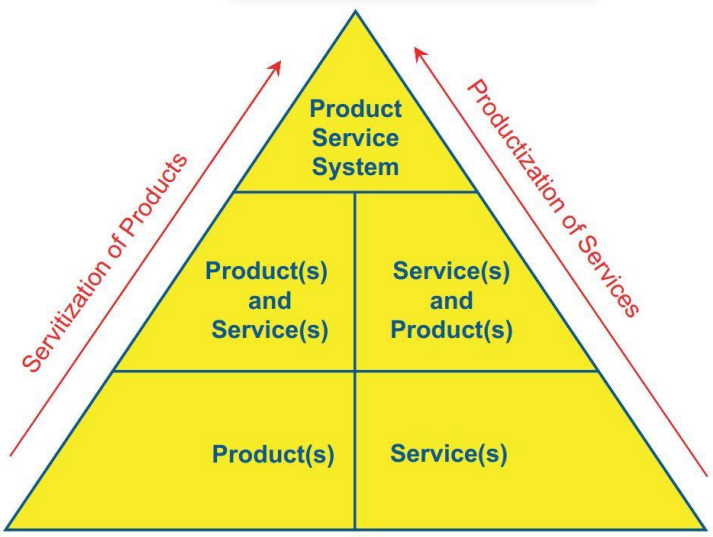

Figure 07: Evolution of the Product-Service System concept, Baines et al (2007)

Parker (2021) proposed that the idea of PSS was formed by a combination of four concepts, namely servitization, dematerialization, eco-efficient services, and the functional economy. PSS approach aligns with the theory of circular economy, it was introduced to deal with resource consumption which results in environmental pressure reduction as well as stimulating economic growth (Parker, 2021; Ellen MacArthur Foundation, 2013)

2.5.1 PSS categories

According to Tukker (2004), 8 types of PSS are categorized into 3 main PSS categories, each of the PSS types is developed to accomplish different goals with different strategies. Each PSS category is classified by the level of servitization as shown in figure 08. A product-oriented stands for a low level of servitization, a use-oriented PSS is an intermediate level of servitization, and a result-oriented is a high level of servitization (Corvellec and Stal, 2017).

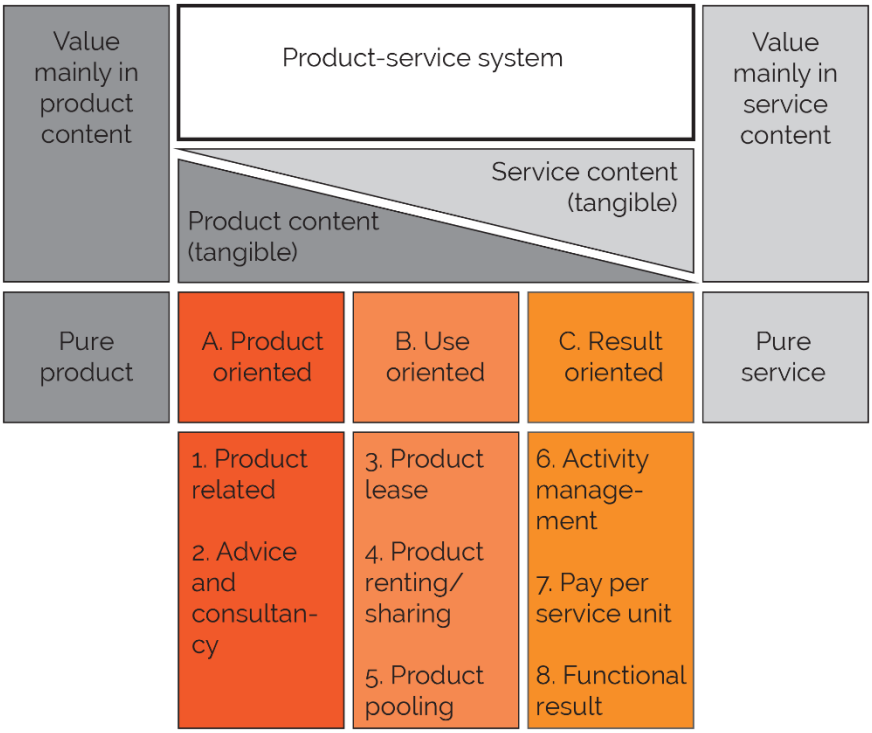

Figure 08: Main and sub-categories of PSS, Source: Tukker (2004), (own illustration)

Product-oriented service

In the first category, product-oriented service mainly focuses on providing products to the consumer, but an extra service is also added as a complementary to the sold products. Product-oriented consists of two sub-categories of PSS which have different approaches.

1. *Product-related service*: In this type of PSS, the PSS provider not only provide products to consumers but also offers complementary service to the sold product during the use phase of the product, such as a maintenance contract and take-back agreement after the product reaches its end of life.

2. *Advice and consultancy*: a provider advises the consumers on the most efficient use of the product, such as customer training, and customer support.

Use-oriented service

In this category of PSS, the product ownership remains at the provider, while the PSS consumer can access the use of the product in different forms such as leasing, sharing, or subscription. There are three PSS sub-categories within the use-oriented service, those three types are elaborated on below.

1. *Product lease service:* A PSS provider own their product and is responsible for maintenance, repair, and control. While the lessee only pays for the use of the product.

2. *Product renting and sharing service:* similar to product leasing, but in this type of PSS, the user could not have unlimited and individual access to the product, unlike product lease service since the product needs to be shared with other PSS consumers.

3. *Product pooling:* is similar to product renting and sharing, but many users can access the products at the same time

Result-oriented service

The last category is result-oriented service which highly depends on the consumers' and PSS providers' agreement, the result or outcome of using the product/ service is determined at the beginning. Result-oriented comprises three PSS sub-categories.

1. *Activity management/ outsourcing:* In this PSS strategy, a PSS provider is hired as a third party (specialist) to achieve something. Since the criteria of this PSS is highly dependent on the result of outsourcing performance, a performance indicator to control the quality of the service is often stated in the contract. A common example of activity management/ outsourcing is catering and office cleaning.

2. *Pay per unit:* In this category, the PSS consumer only pays for the output of the product/ service according to the level or amount of use, the PSS provider remains the owner of the products. An example of this type of PSS is Phillips' lighting, pay per lux

3. *Functional result:* This PSS category is one of the most flexible strategies, the PSS consumer only agrees with a provider of the delivered result. The providers can do whatever to accomplish the consumer's expected result. i.e. consumer needs a "pleasant indoor whether" not HVAC, heater, or ventilation

2.6 Benefits of PSS to the stakeholders and potential of PSS implementation in material leakage minimization

2.6.1 PSS could reduce environmental pressure by optimizing resource utilization

This sub-chapter illustrates why implementing PSS could reduce environmental pressure and what is the potential(s) that PSS offers to minimize material leakage.

The characteristic of PSS that could potentially reduce environmental pressure

Several common characteristics that are present in all categories of PSS could induce material leakage minimization contributors, as follows.

1. The proper product treatment by PSS providers:

PSS is a combination of offering tangible products and intangible services to meet consumers' demands (Tukker, 2004). A maintenance and repair contract is a very common offer that most PSS providers deliver to consumers. Due to the provided maintenance contract, the product is treated (maintenance, repair, upgrade) more properly and efficiently. This can lead to an extension of the product life cycle and optimizing resource (energy and material) consumption (Tukker, 2004).

2. . Delivering the product functionality using the most cost and resource-effective way by PSS providers:

In most PSS cases, ownership of the products remains with the PSS providers who are responsible for the entire product life cycle. PSS providers usually strive for the best profit from delivering PSS. By taking a true life-cycle cost into account in designing PSS production and delivery, optimizing resource consumption brings about higher profit for the PSS providers as the required capital for a resource is reduced. The more optimization of resource utilization the stronger incentive the PSS providers get (Tukker, 2004).

Tukker (2004) reported that the result-oriented PSS, especially the functional result PSS type, has the highest potential for environmental pressure reduction. In this type of PSS, the only commitment between PSS providers and consumers are the agreed result of exploiting PSS. Therefore, this allows the PSS providers to go in the most cost-effective and resource-effective way.

3. Support by specialized facilities and knowledge of PSS providers in PSS implementation:

PSS providers always have great specialized facilities and knowledge to support their PSS operations. One advantage of having such advanced facilities is that it could minimize resource consumption as well as PSS production and management costs (Baines et al, 2007). The PSS production and management costs are reduced due to the economy of scale. Also, the resource could be treated more effectively by the PSS provider's advanced facilities and knowledge.

Material leakage minimization contributors from implementing PSS

PSS could reduce environmental burden by applying various resource-optimizing strategies to minimize both resource extraction and emission during the product life cycle, while the offered product/ service remains the same or better level of quality. Many PSS strategies were developed from different approaches to achieve circular economy goals.

The above-mentioned PSS characteristic could induce to the four main material leakage minimization contributors as follows.

1. *Product life cycle extension*

Product life cycle extension is referred to Slow loop strategies by Mestre and Cooper (2017), operational efficiency, product system substitution, and product longevity by Kjaer et al (2018). The product life cycle is extended by efficient maintenance and repair.

Furthermore, In a material substitution strategy, the residual material of ended life cycle product could also be recycled and used as spare parts/elements to replace another fractured product, which could also lead to the last longer product.

By doing so, the product life cycle is extended which could decrease the need of producing a new product which results in a reduction of virgin resource extraction, waste, and CO2 emission during the production phase.

2. *The efficiency of resource utilization enhancement*

By having the technical knowledge and professional facilities, PSS providers/ manufacturers could optimize their resource utilization while delivering the same or better product value-in-use to consumers (dematerialization). By doing so, not only reduces production costs due to the PSS providers'/manufacturers' economies of scale but also resource consumption and waste generation as it could require fewer resources per use (Baines et al, 2007).

Also, PSS strategies such as product sharing, optimized results, and end-of-life management (reused, remanufactured, refurbished, recycled material) could optimize resource utilization and close the material loop (Kjaer et al, 2018)

3. *Higher waste recovery rate (End-of-life product management)*

Most of the PSS providers are responsible for their whole life cycle product which includes a product responsibility after the end of its life cycle. To contribute to PSS providers' profit enhancement and environmental sustainability, PSS providers have to maximize their resource utilization. One strategy is that the PSS products that reach their end-of-life are not instantly gone to landfills or incinerated, but they are treated according to the EU waste hierarchy for optimizing the resource and closing the material loops. Considering that more residual PSS products or components are being treated properly according to the EU waste hierarchy for being utilized on their second life cycle, fewer PSS products or components are discarded. Therefore, the waste recovery rate of the PSS provider portfolio is higher.

Figure 9: waste hierarchy (source: European Commission, n.d., own illustration)

4. *Product circularity improvement (design for being recyclable, allowing product flexibility in substitution)*

According to Tukker (2004), PSS providers could get more incentives from optimizing resource utilization. Designing PSS products for being easily reused/ recycled is one essential resource optimization feature of PSS that could lead to material leakage minimization. According to Parker (2021), a principle within PSS that is the product's ability to close material loops, design for technological or biological cycles, allows products or components to be easily utilized in the future process could contribute to a circular economy.

Many successful PSS providers, such as Mitsubishi Elevator Europe, developed their products to be easily disassembled as those residual products or components could be readily re-utilized at the end of their life cycle (Zwart, 2020).

A material passport is also an important feature that facilitates product reusing and recycling at the end of the product life cycle. The residual products or components are properly classified and managed to be used in the future within the PSS provider portfolio.

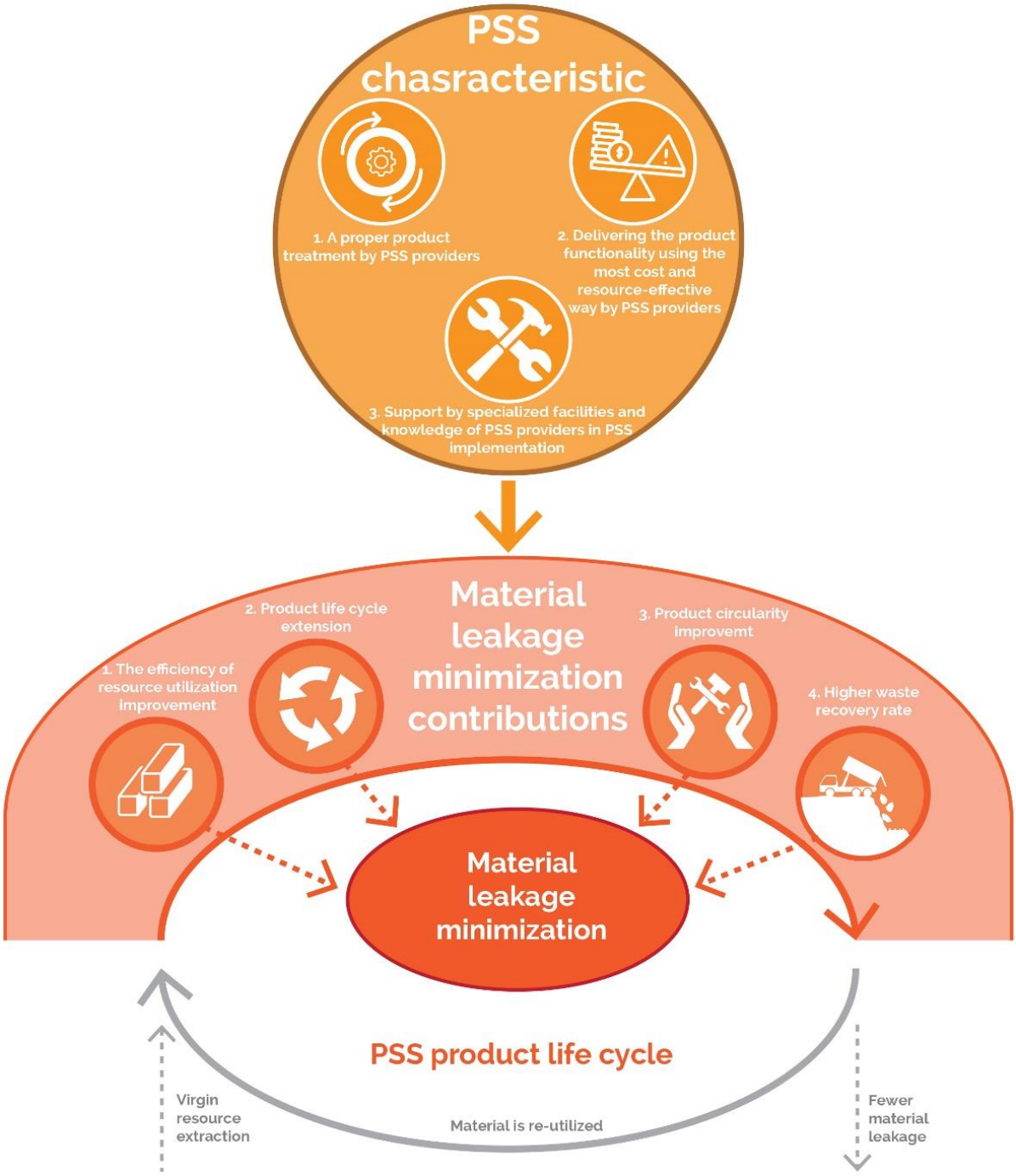

Figure 10: The PSS characteristics which induce material leakage minimization contributors (own illustration)

2.6.2 PSS could optimize CREM at the strategic level (financial aspect)

As corresponding to a circular economy, the two main objectives of PSS are to reduce natural resource extraction while stimulating economic growth by optimizing material/ resource utilization and expanding the material life span (Wetsteijn, 2021).

Since the ownership of (most) PSS product remains at the PSS provider while the consumer only accesses a product functionality in different ways, the PSS provider is responsible for the product throughout its life cycle, the product will be re(used) and recycled more efficiently this could result

in decreasing environmental impact by less natural resource extraction. Therefore, fewer components would go to the landfill at the end of each product life cycle, as long as the product still belongs to or is monitored by the PSS provider it could still be properly exploited or resurrected by a PSS provider for future use. Since less office construction and refurbishment waste are landfilled, the organization's balance sheet could be optimized by decreasing waste management costs.

The paradigm shift in product procurement toward accessing the product functionality in a different way (such as leasing) instead of traditional purchasing could directly benefit the consumer balance sheet as an expenditure of using a product is changed from CAPEX to OPEX. This means PSS could free up consumers' cash while they can use the same product functionality. Besides, the report of Dimache and Roche (2015) stated that PSS can lower the product life cycle cost compared to traditional buying procurement for 3 following reasons. 1.No extra maintenance and repair costs, as these are the responsibility of the PSS provider. 2. Product is used more effectively and longer life span. 3. Product is relatively cheaper due to the attaining of economies of scale. According to David Parker's (2021) finding, many organizations stated that the driver toward using PSS is an accomplishment scope without capital.

2.6.3 PSS could benefit office and office end-user (operational level)

PSS could provide more flexibility and adaptability when the built environments are transformed or the products are obsolete, consumers could change it more easily by asking the PSS provider to change.

Since PSS is formed by partnering between a PSS provider, consumer, and maybe PSS consumer - PSS provider connector (third party), the outcome of the PSS strategy is a tailor-made service that is emerged by the co-creation of every party. Therefore, the provided service is perfectly aligned with the consumers' needs, this also could increase end-user satisfaction as well as the consumer-provider relationship (Strikwerda, 2020).

In addition, since (most) PSS provider is responsible for the whole life cycle of the provided product, additional services to guarantee product functionality and durability such as maintenance, repair, upgrade, or training and consulting services are provided by the PSS provider (Baines et al (2007). By allocating risk and responsibility for the whole product life cycle to the provider, a consumer could avoid dealing with the technical issue of the product. Thereby, PSS could offer more convenience to the end-user, by only paying for product/ service functionality.

2.7 Barriers and drawbacks of using/ providing PSS

Although PSS seems to be a promising procurement that could bring about various benefits including material leakage minimization, implementing PSS could potentially cause negative effects to both the PSS consumer, PSS provider, and environment.

Since most of the ownership of PSS products remains with PSS providers, a consumer might use products incorrectly and carelessly as the product responsibility is allocated to PSS providers. This leads to a shorter product life span and contributes to environmental negative effects (Huer, 2018; Tukker,2004).

Furthermore, by implementing PSS, resource consumption of one product life cycle is likely optimized, but there is a possibility that this might burden another life cycle (Kjaer et al, 2018). For example, a PSS strategy such as product sharing, which means optimizing a resource in the use phase could lead to an increase in product delivery transportation which causes more CO2 emission in the product distribution phase (Huer et al, 2018). This is called a “burden shift” between life cycles (Kjaer et al, 2018).

Sometimes, the shift could occur to another activity. It is called a “rebound effect”. A rebound effect is an effect that occurs when resource optimization leads to a resource deterioration activity caused by people's behavior or systematic responses (Kjaer, 2018). One example is that fuel-efficient cars could persuade people to drive more. Therefore, the result of a rebound effect is unexpected and it might worsen the environmental impact.

Additionally, providing PSS is considered a risky strategy for PSS providers and consumers. On one hand, delivering PSS requires time, sufficient money, and sufficient information on market studying, production, and systematic operating PSS in order to minimize risk and uncertainty that might cause negative consequences in many aspects to PSS providers (Besch, 2004; Baines et al, 2007). Besch (2004) claimed that SMEs could not provide PSS as they do not have sufficient resources to initiate PSS.

On the other hand, PSS consumers require a culture shift in using PSS. Ownerless consumption is a major barrier for PSS consumers (Baines et al, 2007). Many corporations see ownerless consumption as risky and complex in CRE management. In most cases, traditionally, the only owner of the CRE is the corporation. Using PSS in CRE might result in more stakeholder involvement and transaction in the CRE operation (Wetsteijn, 2021). Therefore, there might be higher uncertainties in CRE management as a result of a fragmented organization.

2.8 Building layer

In this sub-chapter, all the building elements regarding PSSs and material leakage are described. According to Stewart Brand's (1994) shearing layer, a building is divided into 6 physical layers, which have different life spans as shown in figure 11. The sequence of 6 shearing layers of Brand's (1994) could influence the design and construction phase, which usually starts from the bottom layer (the layer that has the longest lifespan: site) to the upper layers (structure, skin, service, space plan, stuff) respectively (Pushkar, 2015).

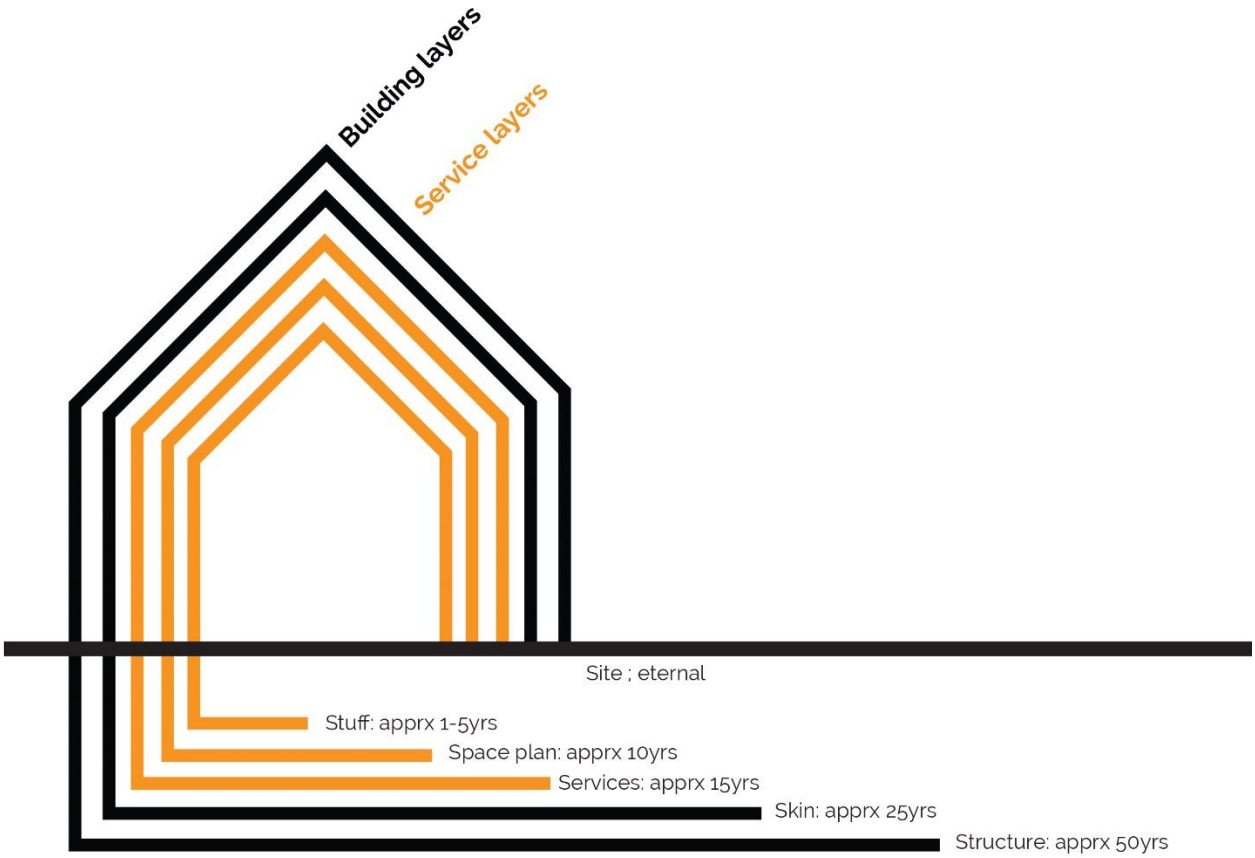

Figure 11: Building six shearing layers. (source: Pushkar, 2015; Brand, 1994, own illustration)

According to Pushkar (2015), Brand's (1994) 6 shearing layers could be simplified by categorizing them as 2 main layers namely, the building and service layers as shown in Table 02. Throughout this research, the terms "building layer" and "service layer" refers to the 2 categorized layers by Pushkar (2015) (see table 02).

Building layers	**Components**
Site	Excavation and landfill
Structure	Foundations, columns, beams, and ceilings
Skin	External walls, external wall covering, roof, and glazing
Service layers	**Components**
Service	HVAC, electrical fixtures, and plumbing fixtures
Space plan	Partitions, floor coverings, and doors
Stuff	Computers, printers, furniture, and light bulbs

Table 02: Components of the six shearing layers. (source: Pushkar, 2015, own illustration)

2.8.1 Does the building layer of Pushkar (2015) generate more material leakage compared to the service layer?

Pushkar (2015) used LCA (Eco-indicator 99 (EI99) with e/e, e/a, h/h, h/a, i/i, and i/a options; as an LCA tool), a cradle-to-grave approach, to evaluate the environmental impact of Brand's six-building layer of a typical multi-story office building in Jerusalem, Israel. The analysis was designed for 50 years period of evaluation. The description of Pushkar's (2015) studied building component is illustrated in Appendix D.

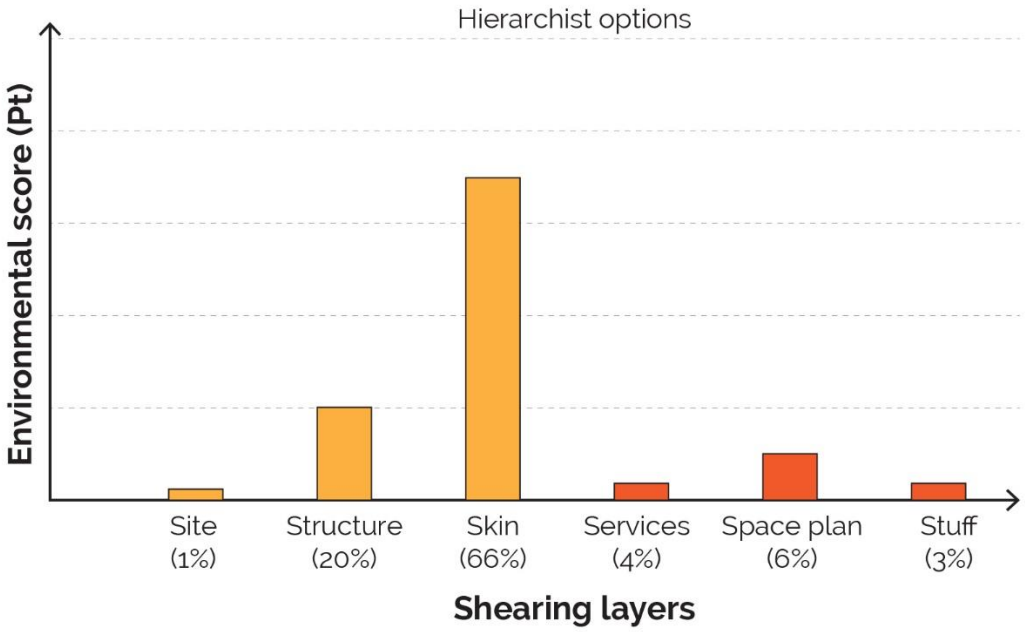

Figure 12: Environmental damage resulting from the Building layers (by different evaluation methods),(Pushkar, 2015) (own illustration)

The findings of Pushkar (2015) indicated the environmental damages from building layers accounted for 85-90%, while the rest 10-15% are service layers, as shown in figure 12. Material leakage is also one of the assessment criteria that contribute to the environmental score.

Pushkar (2015) reported that The Building layer not only requires more material in building a particular construction compared to the service layer but also could generate a lot higher environmental damage (figure 12). Furthermore, the shorter life-span components (service layer) have more opportunities to be replaced by more environmental sustainability or circular components (Pushkar, 2015). By doing so, the environmental impact that is generated from the service layer is likely to be decreased in the future. Therefore, it could imply that the building layer may produce more material leakage compared to the service layer

However, Hardie et al (2011); Freymann et al (2018); BPP (n.d.) argues that the service layer works also cause a significant amount of material leakage. Most of the fit-outs are related to the service layer component of Pushkar (2015). Fit-out projects generate more than double the construction waste compared to typical commercial construction projects. Moreover, fit-out projects usually take place more frequently than other construction projects. Fard Fini and Forsythe (2020) and Casas-Arredondo (2021) reported that the office fit-out usually takes place

every 3-10 years. The fit-outs (mostly service layer components) seem to be major material leakage contributors, but they are often disregarded in the building's environmentally sustainable argument (Casas-Arredondo et al, 2018).

Even though the research of Pushkar (2015) indicated that the building layer works could cause more material leakage compared to service layer works due to the above reasons, many researchers countered that fit-outs (that are mostly service layer works) could significantly contribute to material leakage. An assumption on why the research conclusions between Pushkar and other researchers are different is the use of different research scopes in conducting research.

Until recently, the manifest evidence of study on what are the most material leakage producer between the building layer and service layer of Pushkar (2015) for the office construction and refurbishment project is still limited.

2.8.2 Building layer PSS implementation barriers

PSS is potentially a proactive strategy to reduce the environmental Impact. However, most of the PSS in the market are service layer PSS. There are only a few building layer PSS in the market due to high uncertainty and implementation barriers of the building layer PSS, as follows.

Building regulation

In The Netherlands and many other countries, building layer component is restricted from being provided through PSS due to building regulation (e.g. Dutch building ownership regulation). In the Netherlands for example, Dutch law regarding the ownership, “building right” or “ accession”, stated that everything that is permanently attached to the building and cannot be removed without destroying an asset should belong to the building owner, in another word, it cannot own by the third party (Parker, 2021; Zwart, 2020). In this case, the building layer PSS, such as structure or skin, could not be removed from the building without destroying the asset. It is not possible to be provided as PSS since the ownership of the building layer PSS mostly remains at the PSS provider. This regulation means avoiding the ownership and financial complex uncertainty once the building owner or the provider of provided building layer PSS goes bankrupt (Zwart, 2020; P.B., personal communication, 2022).

Financial related barrier

Other than the building right, the financial aspect of building layer PSS is another uncertainty that is considered a great challenge for implementation. From a Dutch banker's point of view, the building layer PSS could arouse risks for the banker and building owner (P.B., personal communication, 2022). Once the building owner wants to grant an investment loan from the banks or other financial supporters to build a building or office which planned to use building layer PSS, the proposal is generally rejected by the bank or any financial supporter since the residual value of the building and building layer PSS are difficult to be calculated or they probably end up with minus residual value (demolition and striping-out fee are taken into account) (P.B., personal communication, 2022).

More importantly, in case the residual value of the building with building layer PSS is possibly calculated and the result is not negative, a bank or financial supporter must do multiple

complicated financial evaluations of all building value, owner financial risk, and PSS provider financial risk. This seems to be more complicated and unnecessary additional work for them (P.B., personal communication, 2022).

“From my perspective, as a Dutch banker for more than 20 years, no one (banker) would like to do this deal. It is too risky and not worth doing” said P.B (personal communication, 2022)

Building construction management

In the Netherlands and many other countries, construction is usually done/ supervised by the main contractor or project manager. Most of the construction component is already managed or organized before the construction kick-off by a contractor. Using building layer PSS in construction could make construction management more difficult due to arising additional stakeholders' involvement and transactions which could lead to extra costs and delays (P.B., personal communication, 2022; Wetsteijn, 2021; Winch, 2010).

In most cases, the PSS is excluded from project managers or contractors' working scope, if owners want to use PSS, they have to organize (and maybe finance) it by themselves.

According to the aforementioned barriers in implementing building layer PSS, they could be a cause of the building layer PSS amount being close to none in the market.

2.9 Material leakage minimization criterion for using PSSs in the office

According to 2.6.1, the four PSS material leakage minimization contributors are identified, namely **1. Product life cycle 2. The efficiency of resource utilization 3. Waste recovery rate 4. Product circularity (design for being recyclable, allowing product flexibility in substitution).** These contributors are used as PSS assessment criteria for evaluating material leakage minimization of PSS in this research. The level of material leakage minimization of each PSS is in accordance with how far each PSS develops the four contributors. Each criterion has a standard baseline (to be considered whether each PSS is environmentally sustainable/ material leakage minimizing).

In the context where the PSS is used in the office, these material leakage minimization criteria can be used for investigating how material leakage minimization is improved by using PSS products compared to the linear economy product.

2.9.1 The baselines of each material leakage minimization assessment criteria in using PSS in an office refurbishment context.

Since the four material leakage minimization contributors of PSS are set as material leakage minimization criteria, the baseline of each material leakage minimization criterion in using PSS in an office refurbishment context has to be indicated. The baselines defined the minimum value of each criterion that is considered environmentally sustainable.

Product life span (10 years or less):

The components that have a 0-10 years life span are considered not sustainable and have high potential in material leakage contribution. Since the average office turnover period is 3-10 years, the products that have less than 10 years life span might encounter the end of life more than once during the office operation period. This might lead to more product material leakage due to a higher amount of product turnover (Casas-Arredondo et al, 2018; Casas-Arredondo, 2021; Hardie et al, 2011).

One important PSS strategy is to extend the product life span and increase product durability. Once the product lasts as long as or exceeds the average office turnover period, the material leakage from the product is decreased due to less product turnover.

Waste recovery rate (50% of waste recovery rate or less):

European circular economy plan aims to reduce total waste generation and use of primary resources by half by 2030 (European Commission, n.d.). This means in the upcoming years all product waste recovery rates should not be lower than 50%. Meanwhile, the average R&R waste recovery rate so far is 17% while another 83% of it is discarded (Yu et al., 2021). To comply with the European circular economy plan, 50% of the waste recovery rate is set as a baseline for every PSS.

Product circularity (composition of material, design for recycling):

Some materials or components are more difficult to be recycled and reused, for example, hazardous material or contaminated material like asbestos which is possibly recycled but a special facility is required. Mixed waste also requires an additional segregation process before being recycled. Therefore, those elements that are not commonly recycled usually end up being buried, incinerated, or landfilled. According to Fard Fini and Forsythe (2020), asbestos, mixed waste, and carpets (which contain bitumen) are commonly landfilled in Appendix B. To improve product circularity, avoiding the use of toxic components and components that are not able to be directly treated circularly after their end-of-life cycle is necessary.

Product circularity relies on the PSS strategy on product design which means to be reused or reutilized after the end of the life cycle. The strategy that concerns products after the end of the life cycle, such as a modular product, disassemblable product, or material passport, could lead to an improvement in product circularity.

The baseline of product circularity is to ensure that a combination of PSS strategy and the use/ selection of product components has a minimum 50% waste recovery rate at the end of the product life cycle.

The efficiency of resource utilization

Even though the efficiency of resource utilization is one of the four PSS material leakage minimization contributors, it is difficult to set a numeric baseline as different PSS providers use different strategies or facilities for utilizing their resources.

However, resource utilization efficiency is an important criterion to qualitatively investigate particular PSS cases in empirical research on how the provided PSS strategies contribute to material leakage minimization.

2.10 How to substantiate that PSS could mitigate the material leakage and benefit CREM (for empirical research investigation)

Theoretically, although multiple research/ scientific documents mentioned that using PSS in the office or real estate industry could bring about great benefits to PSS providers, consumers, and the environment, there are only several successful PSS cases in offices in real practice. Therefore, the empirical research is to investigate how the current situation of using PSS in the office is and does the office material leakage minimization by using PSS benefits CREM (consumer) as much literature claims.

To investigate how PSS can mitigate office material leakage and bring about benefits to CREM, a PSS category+2 steps framework is formulated through theoretical research. The framework is used as an investigation basis of empirical research (for PSS providers' case) to bridge the gap between literature and practice to review, in real practice, how PSS is working toward material leakage minimization according to the theory. All the aforementioned (possibly) material leakage minimization strategies by PSS are incorporated into this framework. The empirical research investigation is conducted by a pattern matching between the framework and each selected PSS case. The expected result of the investigation using the PSS category+2 steps framework is how/ what strategies each PSS applies to contribute to material leakage minimization.

After investigating the process of how each PSS contributes to material leakage reduction by using the PSS category+2 steps framework, the result of each PSS material leakage minimization contributor is assessed/ evaluated by the material leakage minimization assessment criterion (2.9).

2.10.1 A two-steps framework, How PSS could achieve a material leakage minimization and resource optimization evaluation tool

Once suitable case studies are selected, an evaluation framework is applied to evaluate the case studies' success. A proposed two-step framework by Kjaer et al (2018) is one possible framework that could ensure an accomplishment of PSS for a circular economy (CE).

The two-step framework of (Kjaer et al, 2018) demonstrated how PSS could achieve the CE objective (absolute resource decoupling). The framework consists of various steps that could lead to absolute resource decoupling as shown in figure 14. To ensure the success of one PSS service, the two-step framework could be applied as an assessment tool to validate the compliance of the assessed PSS case to the two-step framework.

The overview of the two-step framework is illustrated below, see figure 14. The framework consists of two main steps, the first step is to analyze PSS and identify the potential of PSS that could lead to resource optimization, while another step (step two) is to identify the challenges and limitations of PSS toward absolute resource decoupling. This analysis or quantifying takes place by applying the Life cycle assessment (LCA) (Kjaer et al, 2018)

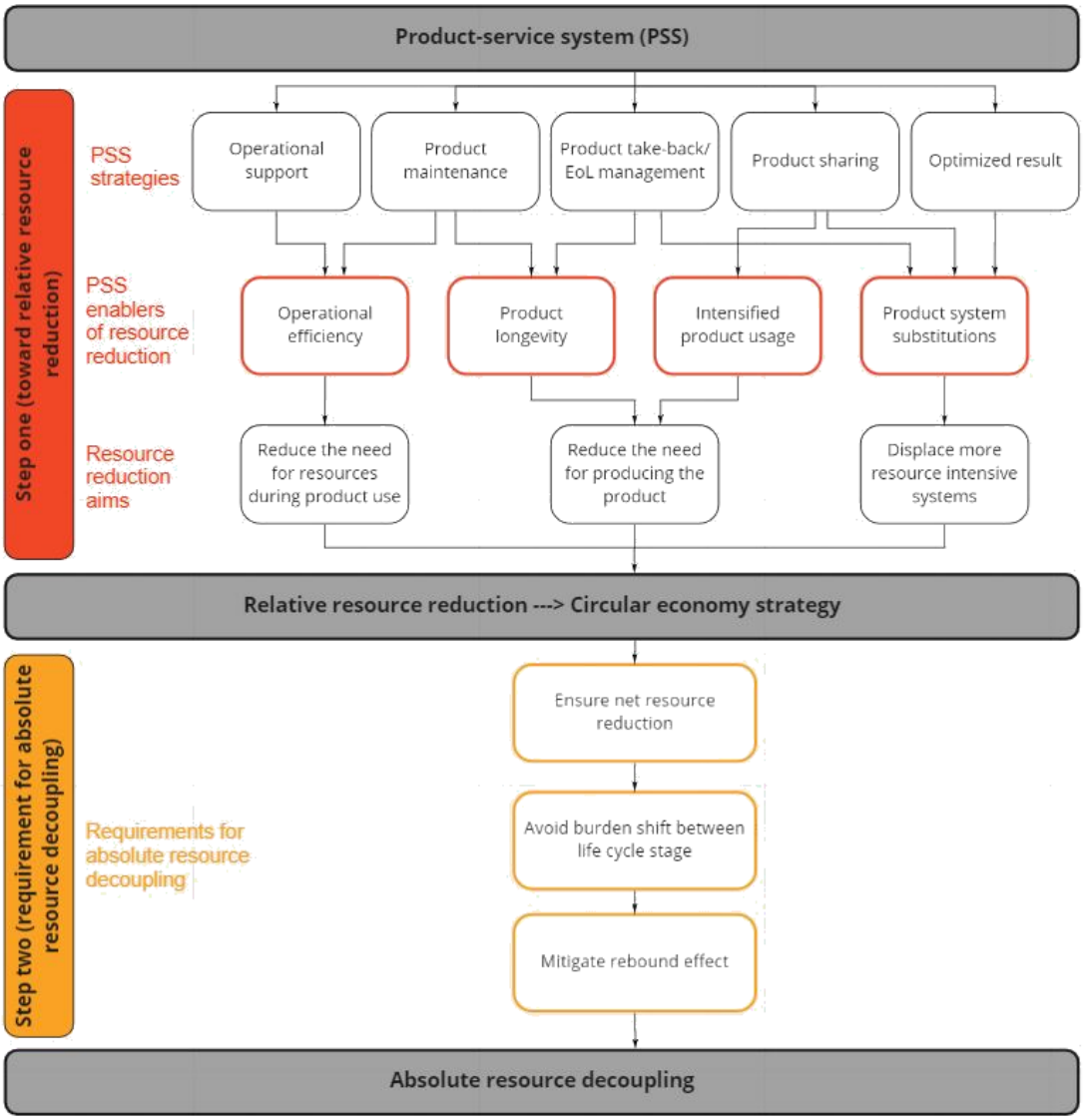

Figure 14: Kjaer two-steps framework, source: Kjaer et al (2018), (own illustration)

Step 1: Relative resource reduction by PSS strategies

In the two-step framework, Kjaer et al (2018) illustrated that four resource reduction enablers are caused by PSS strategies, each resource reduction enabler could lead to relative resource reduction in different approaches. Four resource reduction enablers are elaborated on below.

Operational efficiency:

Operational efficiency is when the resource is used more intensively, such as expanding its life cycle or increasing product durability through proper maintenance and support.

The PSS product could be used more effectively since the PSS provider manages and provides proper maintenance and operational support to the consumer, such as training and advising PSS consumers for the most efficient use of the product (Kjaer et al, 2018). Once the PSS product is used more efficiently, the need for resources during the use phase of the product life cycle decreases (Kjaer et al, 2018).

Product longevity:

The idea of product longevity can be referred to slow loop strategies of Mestre and Cooper (2017), where the material flow is slowed in each phase of the product life cycle. Some linear economy products (such as electronic equipment) have a fast turnover of the product due to obsolescence. Therefore, this type of product generally generates numerous of waste.

Some PSS strategies aim for product longevity by applying End of Life management (EOL) to re-utilizing product components properly (recycling, refurbishment, reusing, or remanufacturing) or proper product maintenance (repair, maintenance, upgrade) to extend product life cycle or close material loop (Kjaer et al, 2018). Once the product life cycle is extended the need of producing products might reduce consequently.

Intensified product usage:

Intensified product usage could be called product sharing. Tukker (2004) considered product sharing as one of the sub-categories of used-oriented PSS. Product sharing is suitable for products that are used occasionally or are used in only a short period. Sharing system could intensify the use of the product during its lifetime, which is more convenient for PSS consumers to rent or lease products rather than buy them. Consequently, the need of producing the product is also decreasing.

Product system substitutions:

Product system substitutions are to shift the way of supporting consumer needs more circularly, for example using a remote video conference instead of traveling to the meeting place. Also, the substitution can take place at a product level, such as reusing products or using recycled material to create a new product that could provide consumers with the same product functionality to optimize resource utilization. Product system substitutions could displace resources more intensively toward net resource reduction.

Step 2: Ensuring absolute resource decoupling

To accomplish absolute resource decoupling, these three subsequent requirements need to be met. Three requirements are net ensure resource reduction, avoid burden shifting between life cycle stages, and mitigate rebound effects (see figure 14).

Ensure Net Resource Reduction:

To ensure that all the relevant alternatives and processes of PSS are taken into account for the environmental performance evaluation of PSS. Net resource reduction depends on the avoided resource (the reduced resource from using PSS strategies to optimize resource utilization) and incurred resource (extra/ additional resources which are needed for operating PSS) (Kjaer et al, 2018). The equation of net resource ensuring is illustrated as:

"Net resource reduction = avoided resources − induced resources"

Avoid Burden Shifting between Life Cycle Stages:

During the product life cycle, optimizing one phase in the product life cycle might shift the burden to the other phase (increase resource consumption) (Kjaer et al, 2018). For instant, using a technique with a lower operational energy consumption might need more material in the production phase (Meijer, 2021). Avoiding burden shifting is considered a complicated method, one possible way is to expose and quantify the environmental pressure aspect as much as possible throughout the product life cycle by applying Life Cycle Assessment (LCA) (Meijer, 2021).

Mitigate Rebound Effects:

To achieve absolute resource decoupling, rebound effects have to be controlled and mitigated. The rebound effects are phenomenal that occurs when the actual product resource consumption improvement is less than what it should be since the improvement could urge people to use more products/services (Kjaer et al.,2018). For example, when more fuel-efficient cars are invented, people tend to drive more.

Conclusion: the two-steps framework as a PSS assessment tool

The two-step framework shows how PSS could achieve absolute resource decoupling (objective of CE). To ensure the success of PSS toward the CE objective (absolute resource decoupling), the two-steps framework of Kjaer et al. (2018) is applied as an assessment or evaluation tool for the investigated selected PSS (case studies) by pattern matching (investigate whether the selected PSS properly complies with each step of the two-steps framework).

Additionally, at the end of step one, relative resource reduction is also one of the important indicators of material leakage minimization after applying PSS in the office.

2.10.2 PSS categories + two-steps framework

The framework is formulated by a combination of the PSS categories model of Tukker (2004) and the first half of Kjaer et al (2018) Two-step frameworks (only step one) which illustrate how different PSS categories/ types/ strategies lead to resource optimization or material leakage minimization.

The PSS categories model of Tukker (2004) describes 8 types of PSS within 3 PSS categories. While the two-step framework (only step one) introduced by Kjaer et al (2018) illustrates how PSS could minimize material leakage and optimize resource consumption while offered product functionality or quality remains unchanged or better. The combination of the two framework shows the overview of how each type of PSS that offer PSS differently could minimize material leakage.

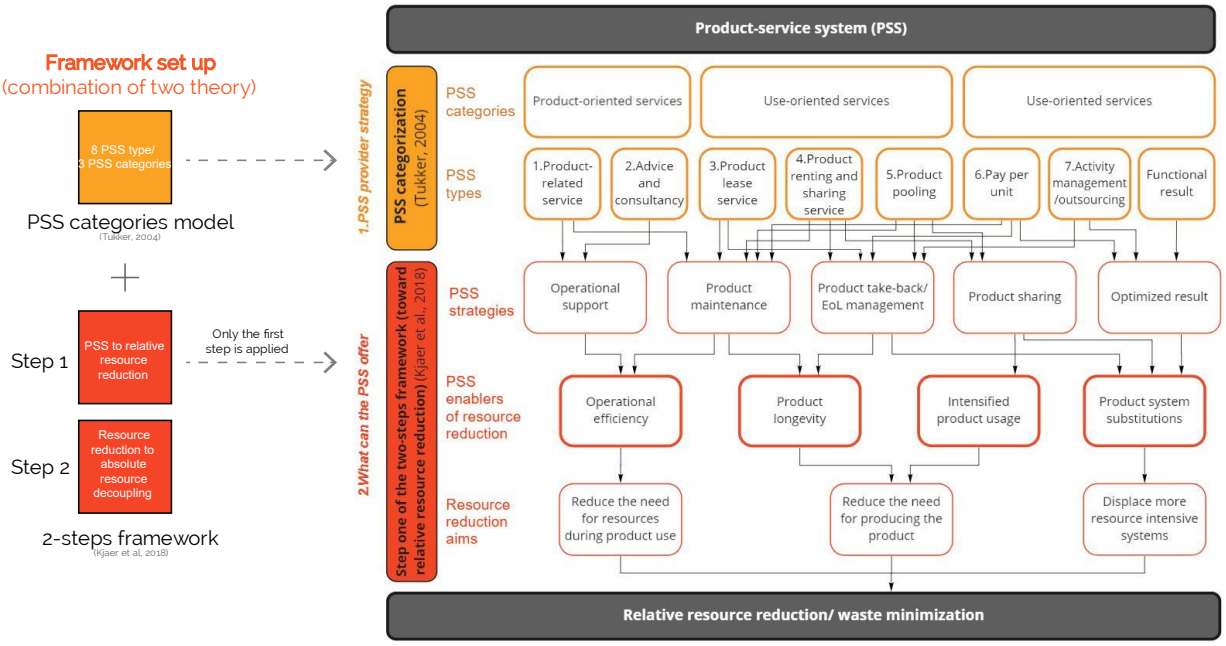

Figure 15: PSS categories + 2-step framework (own illustration)

Other than material leakage minimization, additional values such as additional service, financial advantages, and flexibility, are great advantages of using PSS which could be investigated by using the PSS category + 2-step framework.

Note: The purpose of deriving only the first step of Kjaer et al (2018) two-step framework to a PSS category + 2-step framework, while the second step is excluded, is that 1. The first step of Kjaer et al (2018) two-step framework already provides sufficient information to cover the main aspect of investigation for using PSS in the office regarding material leakage minimization. 2. Due to the time limitation in research, incorporating and studying the second step of Kjaer et al (2018) two-step framework in empirical research is not feasible since the second part requires LCA studying.

CHAPTER 3:

EMPIRICAL RESEARCH DESIGN AND METHODOLOGY

3. Empirical research design and methodology

3.1 Empirical research design

The empirical research is conducted through multi-case studies of the PSS providers (supply), PSS consumers (CREM), and other PSS-related professionals, to understand deeply and comprehensively the applying PSS to offices in a real practice context from a different point of view. In-depth interviews and case-related literature reviews are the main investigation methods of case study data collection. The outcome of the empirical research is developed from a combination of different sources of information (also information from different parties). Subsequently, an empirical research finding will be applied to formulate the answers to the thesis questions.

The case study mainly focuses on the PSS provider as they can provide information on the entire life-cycle of PSS regarding the provided PSS and material leakage-related aspects. Meanwhile, PSS consumers and other PSS-related professionals could provide different perceptions and information about PSS regarding material leakage minimization. A combination of all case studies findings is essential content for research findings.

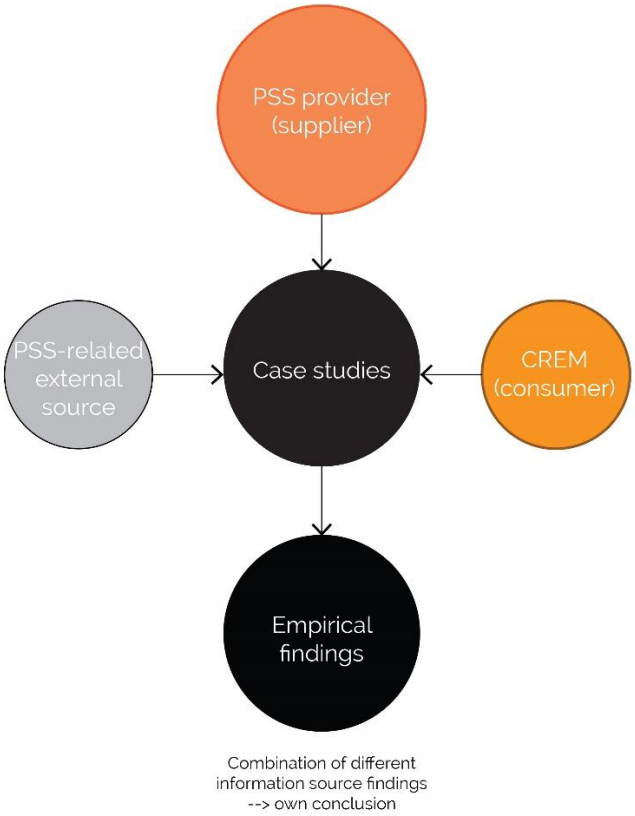

Figure 16: Stakeholders address in the cases study (own illustration)

A case study strategy is designed by referring to Yin's (2002) chapter 2. One important step is to plan a case study design, a blueprint of the research that could precisely illuminate the research question and direction (Yin, 2002).

3.1.1 component of research design

Yin (2002) introduced five components of the research design as an essence of a case study research plan namely, the case study question, case study proposition (process toward an answer to the case study question/ achievement), unit(s) of analysis (scope of analysis), the logic of linking the data to the proposition, and the criteria for interpreting the findings. For this research, those components are indicated as followed.

Research question (case study):

- How does PSS work for contributing to office material leakage minimization?
- What are the benefits and barriers of implementing PSS?
- What are the benefits for the office of applying PSS regarding material leakage minimization?

Proposition:

- Study of how successful PSS cases in the office could minimize material leakage.
- Study how each type of PSS contributes to material leakage minimization (In real practice).
- How PSS could provide benefit to the consumer.

Unit(s) of analysis:

- PSS product in an office
- A benefit of PSS to the office
- Material leakage minimization
- Differences and similarities between each case study and between theory and real practice regarding material leakage minimization contribution

The logic of linking data:

- Pattern matching between “PSS categories + two-steps framework” and the selected PSS cases
- Relationship/ connection between material leakage minimization and benefit of PSS to the office (CREM)

Criteria:

- Relative resource reduction/ the amount of minimized waste from a particular product after applying PSS (improvement in 4 material leakage minimization contributors)
- The compliance of PSS (in real practice) to the mentioned frameworks (theory)
- PSS strategy to minimize material leakage
- Benefits and barriers of implementing PSS

3.1.2 Basic type of case study design (2x2 matrix)

Yin (2002) proposed the 2x2 framework which demonstrates 4 types of case study design as shown in figure 17. The vertical axis of the diagram (figure 17) represents the number of case studies which is/ are conducted (single or multiple-case design), while the horizontal axis represents how specific or deep the investigation is in each case study, the horizontal axis also consists of two types of analysis, holistic and embedded.

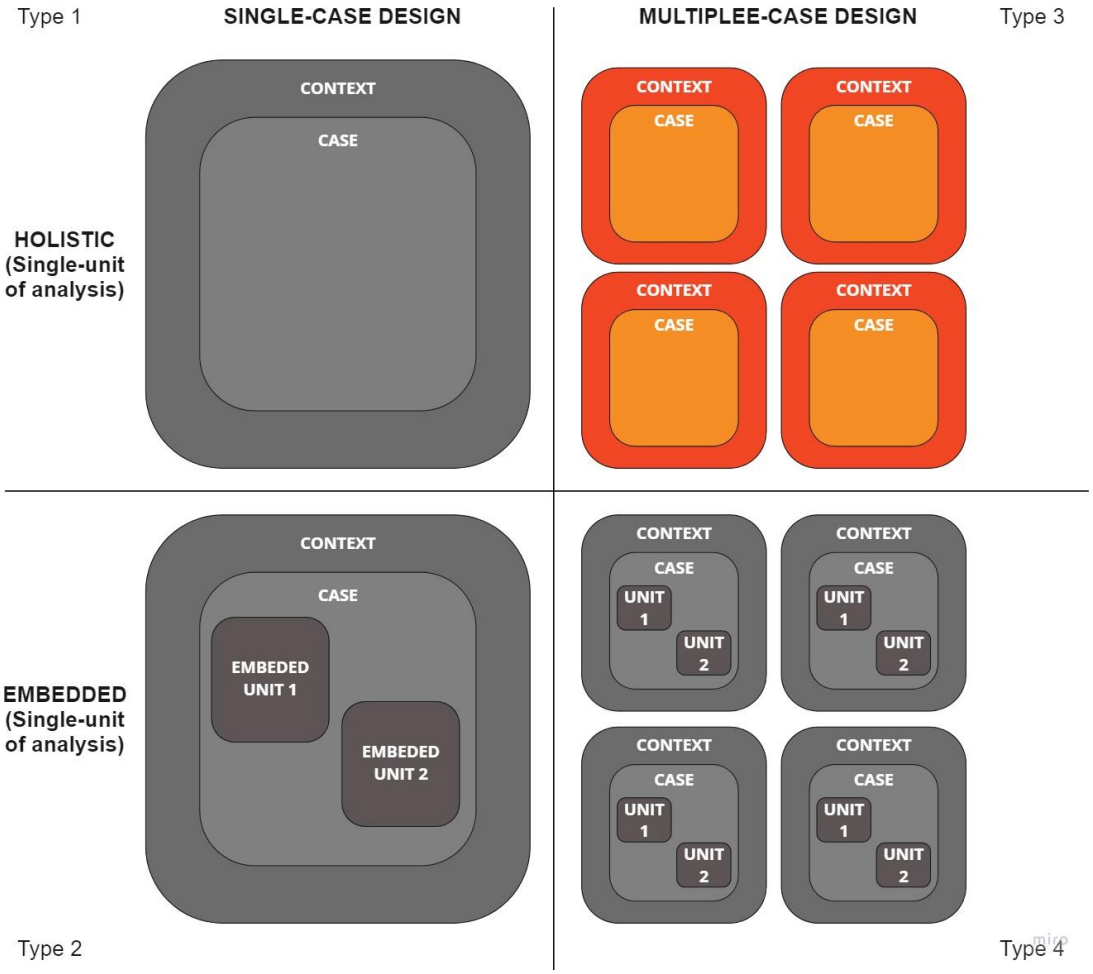

Figure 17: 4 types of case study design (2x2 framework), Source: Yin (2002), (own illustration)

In this research, the multiple-case design with holistic analysis is chosen as a case study strategy. One of the advantages of the multiple-case design is the comparability between cases. The comparability of distinction and similarity between each case could not be done in a single-case investigation. The holistic analysis approach is an investigation of the entire case, it is suitable when there is no logical subunit investigation needed (Yin, 2002). For this research, it is more important to investigate each case study holistically since it is mainly focused on the provided PSS regarding material leakage minimization and resource optimization, therefore, there is no deeply specific sub-unit investigation need. Also, investigation as an overview could make the researcher see the relationship of each aspect within the case study broader.

3.2 Case study selection criteria

The case studies are selected based on the determined criteria to scope down the research territory for more precise and rational findings. According to Yin (2002), case study criteria can be divided into required and desired criteria. The required criteria are to define the minimum requirement of the case studies to be investigated, while the desired criteria are preferred.

To select cases for empirical research studying, the three different PSS-related information sources (PSS providers, PSS consumers, and other PSS-related professionals) are selected differently since the objective of the investigation is different. Three sets of case selection criteria for each PSS-related information source are established as shown in Table 03

Case study selection criteria of the three different PSS-related information sources (stakeholders)

	Supply-side (PSS provider)	**Demand-side (Office/ CREM)**	**Other PSS-related professionals**
Required criteria	1. A representative from the PSS provider is available for an interview	1. A representative from CREM is available for an interview	1. A representative from other PSS-related professionals is available for an interview
	2. The successful PSS provider that provides PSS to the office	2. Medium and large-sized corporation	2. Other PSS-related professionals who can provide an overview of the current situation of PSS in a particular industry which is provided to the CRE.
	4. PSS provider that offers at least one of the PSS categories of Tukker (2004) (Product-oriented service, use-oriented service, result-oriented service)	.	
Desired criteria	5. PSS providers have another circular economy strategy in offering products to the office.	4. Corporate real estate that has experience in using more than one PSSs in the office.	2. Has insight knowledge of the entire life cycle of a particular PSS product.
	6. PSS providers who have not yet ready to offer PSS:	4. The representative from CREM who had encountered various office refurbishment	
	7. Both representatives from PSS providers and Consumers (office/ CREM) in the same project are available for an interview		

Table 03: Case study selection criteria, (own illustration)

3.3 Data collecting objective of each PSS-related information source and introduction to case cases/ interviewees

Since the different PSS-related information sources (PSS providers, PSS consumers, and other PSS-related professionals) are investigated differently. The data-collecting strategy and interview plan of each PSS-related information source are set up separately. However, all the case studies adhere to the same investigation scopes which are 1. Case study company background 2. PSS-related aspect 3. Material leakage minimization-related aspect. In this sub-chapter, the data-collecting strategy and the data-collecting objective of different PSS-related information sources are elaborated.

3.3.1 PSS provider

<u>The objective of data collecting and interview questions sequence:</u>

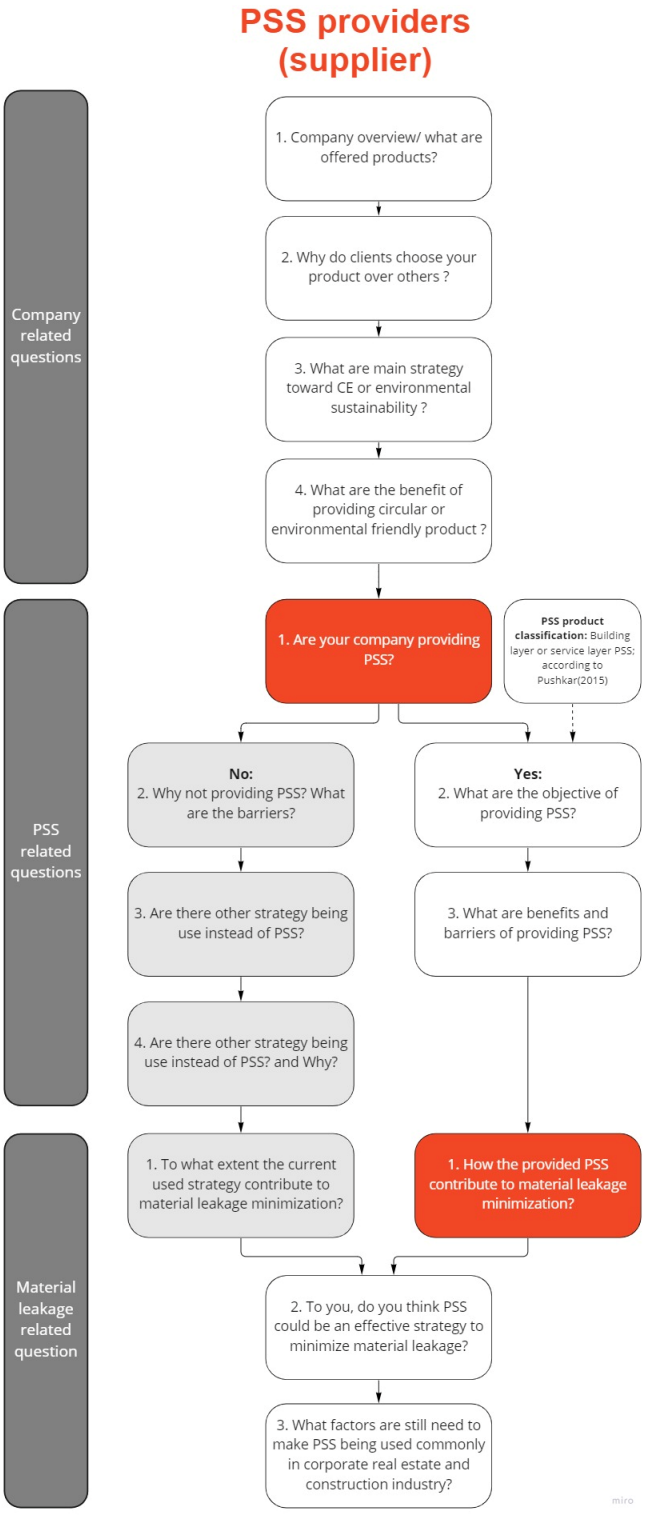

Figure 19: PSS provider interview question sequence (own illustration)

The main objective of investigating PSS providers in empirical research is how the PSS providers offer, treat, and monitor their products throughout the product life cycle. And how the provided PSS contributes to material leakage minimization.

In addition, other PSS implementation-related aspects are also studied, such as the benefit and barriers to implementing PSS. Lastly, the opinion of the PSS provider toward material leakage minimization by PSS is questioned.

For the PSS provider case study, the investigation is conducted by using The two-step framework as the main investigation tool and material leakage minimization contribution threshold as an evaluation of the material leakage minimization improvement after providing the product as PSS. The investigation is done by analyzing the data from an interview (primary data) and case-related literature (secondary data).

Introduction to cases/ interviewees:

1. Elevator as a service (Company M):

Company M has been a top elevator and escalator professional manufacturer for many decades. For more than 70 years, company M has been a representative of one of the most famous electric appliance companies in the European region (Company M publication, n.d.). The company has the vision to move toward “a more sustainable business model for the elevator industry” (Company M publication, n.d.). Company M has developed the circular vertical mobility solution model. It adheres to the quality-driven product/ service, therefore the circular vertical mobility model could achieve more product sustainability by offering higher quality products/services compared to the other elevators in the market (R.K., Head of sale in Company M, personal communication, 2022)

Interviewee:

Name: R.K.

Position in the company: Head of the sale in Company M

2. Dutch furniture as a service company (Company A):

A Dutch well-known and largest office furniture company was established more than a century ago. The company is providing office furniture and space solutions globally. Environmental sustainability is one of its main goals alongside creating vitalizing workspaces (Company A web page, n.d.). In addition, the company has established major facilities which mean to facilitate company activities toward providing circular and environmental sustainability furniture (P.S. personal communication, 2022). Moreover, since the company has a high reputation and strong financial position, the company also act as an intermediary between consumers and other furniture company (P.S. personal communication, 2022).

Interviewee:

Name: P.S.

Position in the company: Product manager and IT specialist CAD

3. Circular carpet (Company I):

A company I was founded in 1973, it has been an international specialized carpet tile manufacturer for commercial clients (Company I related literature 1, 2021). From 1994 to 1996 the company became aware of the environmental impacts since that Interface set its manufacturing standard toward a more sustainable approach to minimize the environmental pressure from its manufacture. Mission Zero was established as a company mission, the achievement of mission zero is to generate zero environmental impact by 2020. Nowadays, they established a new road map called “Climate take back” (Company I related literature 1, 2021).

Interviewee:

Name: J. L.

Position in the company: Sustainability Manager Northern Europe

3.3.2 PSS consumers (CREM)

The objective of data collecting and interview questions sequence:

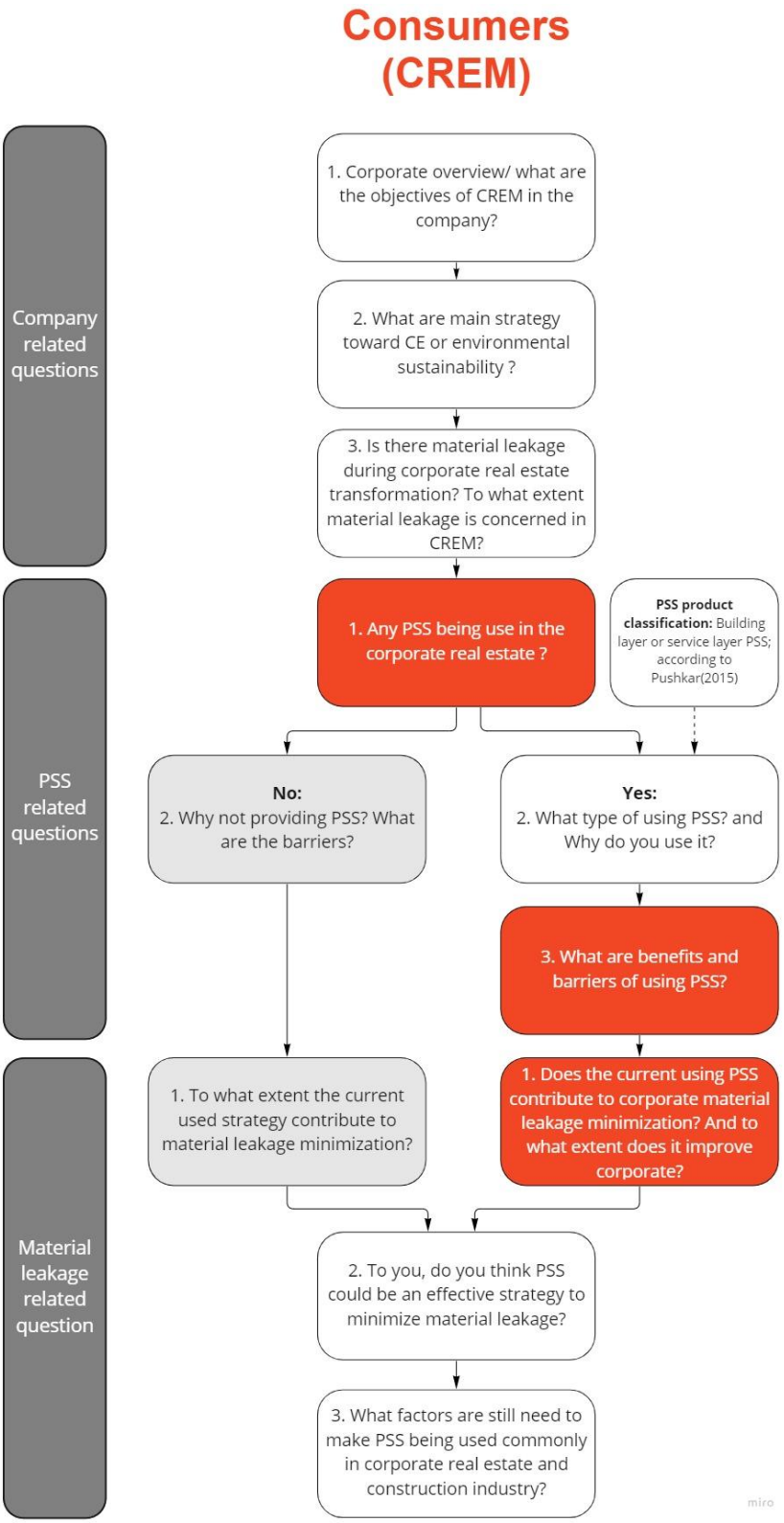

Figure 20: PSS consumer (CREM) interview question sequence (own illustration)

A vision of corporate real estate toward material leakage and reasons to use or not to use PSS from a PSS consumer perspective is prioritized information. Besides, the opinion on using PSS to minimize material leakage in consumer CRE is asked.

The investigation is done by analyzing the data from an interview (primary data) and case-related literature (secondary data).

Introduction to cases/ interviewees:

1. Fast fashion shopping store (Company P):

Corporate P is a newly emerged Asian fast-fashion online store. It was founded in 2013, a corporate P headquarter is located in Bangkok, Thailand. Even though corporate P's main business is driven through an online shopping platform, physical stores are necessary components in running its business. The physical store is a place to connect customers with corporate P products, where customers can touch, feel, and try fast-fashion products firsthand (K.A., Pomelo store development, and designer, personal communication, 2022)

Interviewee:

Name: K.A.

Position in the company: Corporate P store development, and designer

2. International industrial and manufacturing company (Corporate V):

Company V is a Dutch large manufacturer that runs many businesses such as car manufacture, high-tech supply, production and sale of buses, and plastic processing that was established 70 years ago.

Interviewee:

Name: M.B.

Position in the company: Corporate real estate manager

3. Top Dutch university (Corporate E):

University E is the top 5 best universities in the Netherlands and among the top 150 of the world's best universities (QS World University Rankings, 2022). University E was established around mid 19th. The corporate real estate of the university E is considered an immense area, 300,000 sq.m. which includes university facilities, a sports complex, student housing, etc

Interviewee :

Name: D. P./ S.H.

Position in the company: Director of Real Estate/ strategy & consultancy manager

3.3.3 Other PSS-related professionals

The objective of data collecting and interview questions sequence:

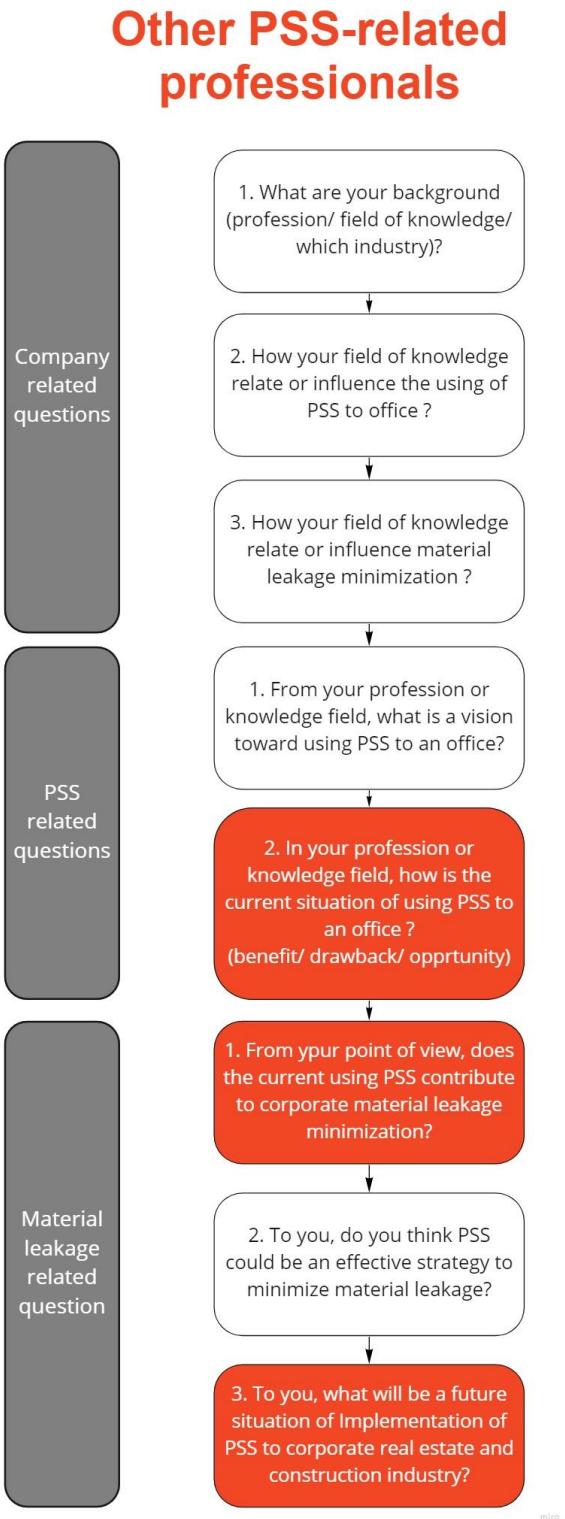

Figure 21: Other PSS-related professionals source interview question sequence (own illustration)

Case studies of other PSS-related professionals aim for investigating a situation of PSS in each professional field of knowledge, such as the furniture industry or building window industry, to grasp the overview of PSS state-of-art. External factors that influence implementing PSS for the office are also the essential information to be explored.

The investigation is done by analyzing the data from an interview (primary data) and case-related literature (secondary data).

Introduction to cases/ interviewees:

1. Knowledge organization for leasing professionals in the Netherlands (Company L)

Company L is a knowledge organization for leasing professionals and a representative of a company that provides leasing products in the Netherlands. Company V was founded in 1972. Company V is focusing on a wide range of business assets leasing such as trucks, machinery, industrial equipment, copy machine, and IT solutions.

Interviewee:

Name: P.B.

Position in the company: managing investor of Company L

2. Furniture design company in Thailand (Company T)

Company T was founded in Bangkok Thailand by a new generation of furniture designers. Most of the company T product is outdoor and office furniture which emphasize aesthetic and ergonomic design.

Interviewee:

Name: V.C.

Position in the company: Furniture designers & Company T owner

3.4 Overall case study process (empirical research)

The empirical research (case study) is consist of three main phases as follows.

1. *Case selection;*

Case studies are selected according to the case study selection criteria (3.2). Three different PSS-related information sources of case studies (PSS providers, PSS consumers, and other PSS-related professionals) are selected and investigated differently.

Nevertheless, the main objective of all case studies is to investigate the use of PSS in the office regarding material leakage minimization.

2. *Investigation phase (conduct case study);*

After the cases are selected, an investigation of each PSS-related information source is done differently to comprehensively explore information and point of view regarding PSS and material leakage minimization.

The investigation of PSS providers is to determine how the product/ service contributes to material leakage minimization after being provided as PSS. And how the PSS provider do to minimize material leakage during offering the product as a service. The investigations (of PSS providers' cases) are conducted by applying PSS categories+2 steps framework as an investigation tool to find out how different PSS providers do to minimize material leakage and optimize resource utilization during offer their product as a service to the consumer in real practice.

Meanwhile, the objective of PSS consumer case studies is to analyze the corporate vision toward material leakage minimization, a reason to use or not to use PSS, and drivers to choose and barriers to not choosing PSS. This would provide insight of PSS on material leakage minimization from the CREM point of view.

Lastly, other PSS-related professionals' information about the current situation of PSS in their field of knowledge is investigated through the interview. By doing this, an overview of PSS nowadays and essential factors that influence PSS implementation are explored.

3. *Evaluation phase (case study analysis);*

Subsequently, the gathered information is analyzed in order to answer the research questions.

PSS provider; After the procedure to minimize material leakage in the office PSS is analyzed by using the PSS categories+2 steps framework. The end outcome/ result of its material leakage minimization of each office PSS has to be evaluated to prove whether PSS contributes to material leakage minimization. The material leakage assessment criteria are used as an evaluation tool that compares each attribute (Product life cycle, efficiency of resource utilization, Waste recovery rate, and product circularity) between the office component that is provided as linear economy products and PSS which is investigated in the empirical research.

Consumer (CREM); What are the drivers of using PSS? And to what extent is a material leakage minimization from using PSS concerned by CREM? The answer to these questions from the PSS

consumer could provide insight qualitative information about using PSS regarding material leakage minimization from a consumer (CREM) perspective.

Other PSS-related professionals; A PSS prevalence in the market and external factors that influence PSS implementation is evaluated to identify the overview and current situation of PSS in a particular industry and context.

3.5 Data analysis

All case studies are conducted by having frameworks as an investigation basis and the material leakage assessment criteria as a result evaluation tool. Subsequently, each case study is analyzed to draw a conclusion and summary before conducting a cross-case analysis. The empirical research findings are used for comparison with theoretical research findings before finalizing them as a research outcome.

All the interviews transcribe will be analyzed in Atlas. ti software. Atlas.ti could label the recurring codes which could correspond to the concepts that were determined in the theoretical research such as “Product-service system” or “material leakage”. Besides, there is a possibility of the newly emerged code which is also essential to the research findings.

The coding process could facilitate in organizing of data according to the determined concept of the theoretical framework. This process can assist a researcher in information comparison which is significant for cross-case studies.

3.6 Data Plan

The data plan indicates how the data is managed effectively, efficiently, and confidentially during and after the research is conducted. All the collected data (raw or primary data) which are audio files or videos of interviews are kept confidentially in private hardware (offline) i.e. personal hard drives or researcher laptops. Some significant primary data might be also backed up online (i.e. google drive or digital cloud). After the research is completed and submitted to TU Delft Educational Repository, all the related data that have been collected will be stored for a year before being permanently deleted. All of the related information will not be shared with anyone outside of the primary researcher or author and TU Delft’s supervisor who has been involved in the research procedure. The information of interviewee, personal information, will not be kept privately anonymous and not be shared with anyone.

The primary data of the research must be protected based on the standards of TU Delft on Ethics and Privacy Committee. All research interview participants have been informed about the research interview protocol before the interviews were conducted which is for the participants to consent to share the information with a researcher to be used for research purposes only.

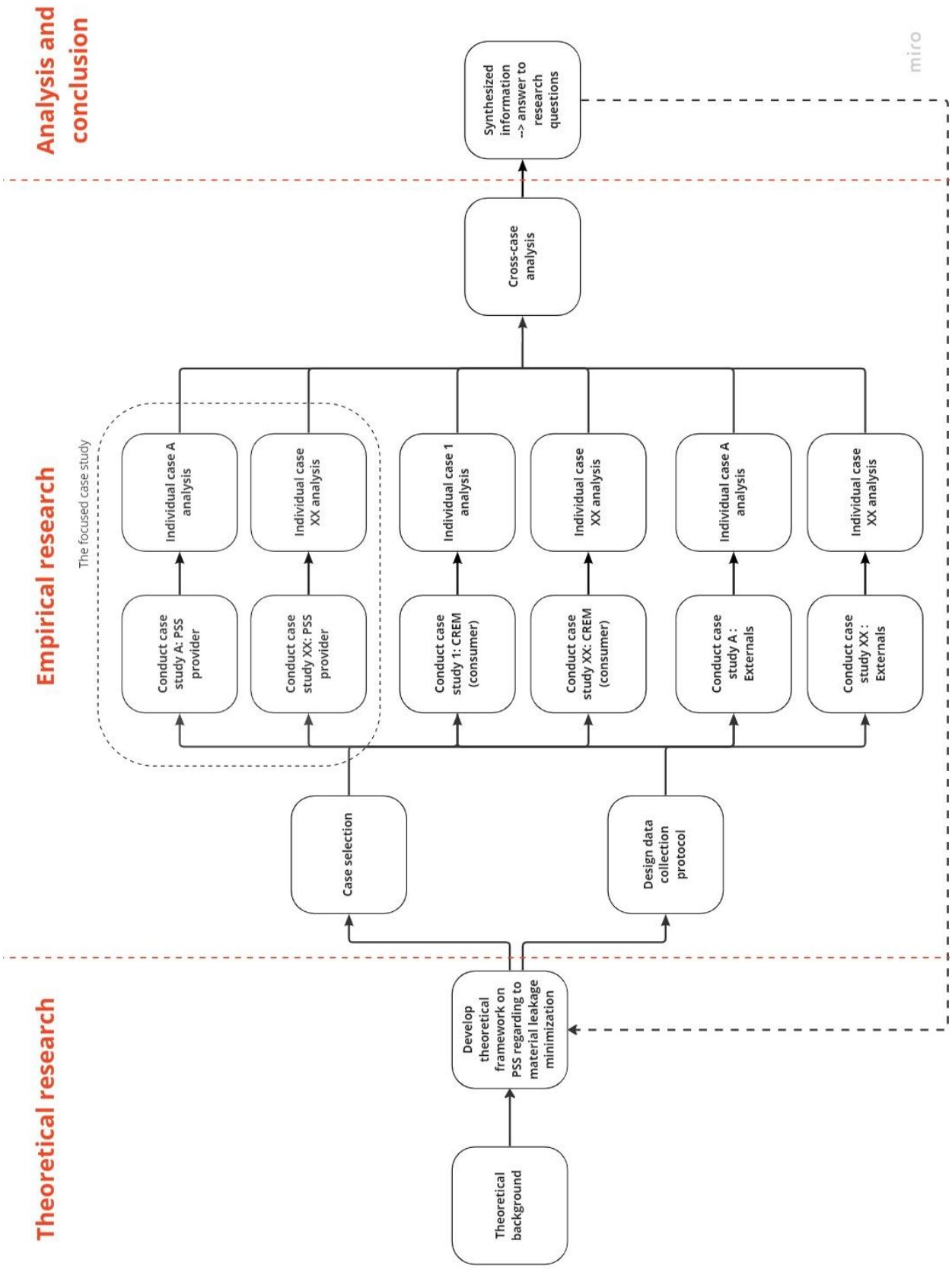

Figure 22: an overview of the research design and procedure (own illustration)

CHAPTER 4:

EMPIRICAL RESULT

4. Empirical research result

A case study focuses on the main aspect of the information gathering objective namely company background, PSS-related aspect, and Material leakage minimization-related aspect. The investigation of the individual case is conducted by semi-structured interview. Different sets of interview questions are used for different PSS-related information sources (stakeholders) as seen in 3.3.

4.1.1 Phase 1: Individual case and analysis of PSS provider (supply side)

Case 1: Elevator as a service (Company M):

Company background and propositions offered by a PSS provider

Company M, a famous elevator and escalator professional manufacturer for many decades in Europe. The company has been driven by the idea of providing “quality-driven” products to the market. According to R.K. (personal communication, 2022), company M has a high reputation for providing great elevator and escalator products in the European market.

Company M had provided all of its products as a traditional model (linear economy) until 2015 when it had a project in the Netherlands, where the owner and developer of the project decided to build this project under the concept of an entirely cradle-to-cradle approach (Company M related literature 1, 2020). The enthusiastic collaboration of the owner and others in the project consortium drove and motivated company M to do its best in R&D for the PSS elevator proposal (Zwart, 2020).

Since that, company M saw the market opportunity to increase its market share and to achieve a breakthrough in the current split incentive problem of the traditional linear construction world by selling/ providing the elevator as a service (R.K., personal communication, 2022). Due to the great financial stability, facilities, and connection of Company M, it did not difficult to start providing an elevator as a service to the market. To ensure that the elevator as a service model becomes financially successful, company M hired a famous international audit firm to evaluate the true value of this model (elevator as a service (leasing) vs traditional model (owning)) for 30 years estimation duration. According to Company M-related literature 2 (2016), the Total Cost of Usage (TCU) and other external costs namely, environmental and socio-economic costs were calculated (Company M-related literature 1, 2020). The result of the famous international audit firm calculation showed that elevator leasing is a more reasonable choice from both financial and social perspectives, it not only saved 13,127 Euro for 30 years period but also significantly reduce energy consumption and material leakage (see figure 23) (Company M related literature 1, 2020).

However, according to Company M-related literature 2 (2016), there are still some weaknesses of this model namely, the long distance of product and service transportation and the high rate of raw material consumption was pointed out by a famous international audit firm (2016). At this moment company M is working toward mitigating this issue and they believe that it will be solved in a couple of years. New factories and distribution warehouses have been established throughout the EU countries to solve the long-distance transportation, meanwhile a circular approach of an elevator as a service will soon close a material loop which could contribute to material leakage minimization (R.K., personal communication, 2022).

The elevator is considered a service layer according to Pushkar (2015), but some part of it such as the elevator shaft is attached to the building. This may result in a challenge in the building permit approval phases and construction phases due to Dutch building regulations. According to the Dutch building law, “building right” or “accession”, stated that everything that is permanently attached to the building could not be owned by a third party (PSS provider) (Parker, 2021; Company M related literature 1, 2020). In this case, there are some parts of the elevator such as the elevator shaft or the electrical and mechanical system that need to be permanently attached or embedded in the building. Therefore, if the elevator as a service is completely owned by company M, it is not feasible as it contradicts the building law. The solution to overcome this problem by company M is that ask the main contractor to build or prepare the building's attached (such as shaft) elements before company M provides the rest, such as elevator car and systems, as a service (Company M related literature 1, 2020).

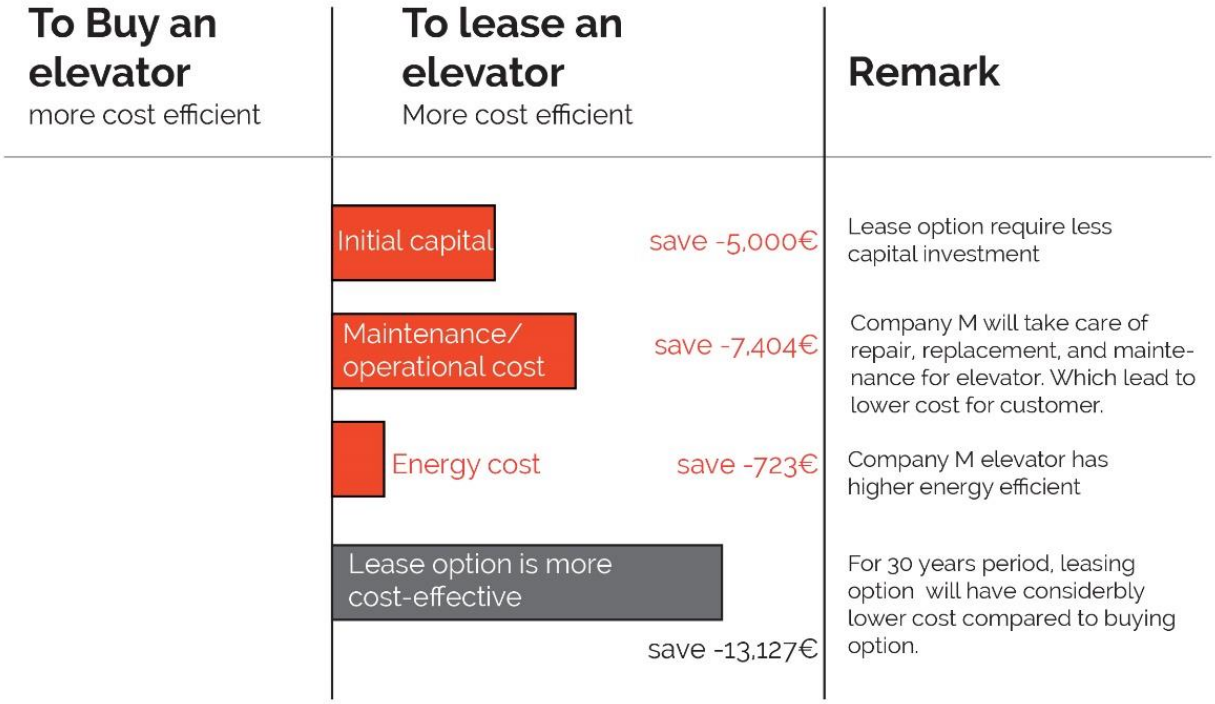

Figure 23: Total cost of ownership comparison (between M-use and buying conventional elevators), Source: Company M related literature 1 (2020), Company M-related literature 2 (2016) (Own illustration)

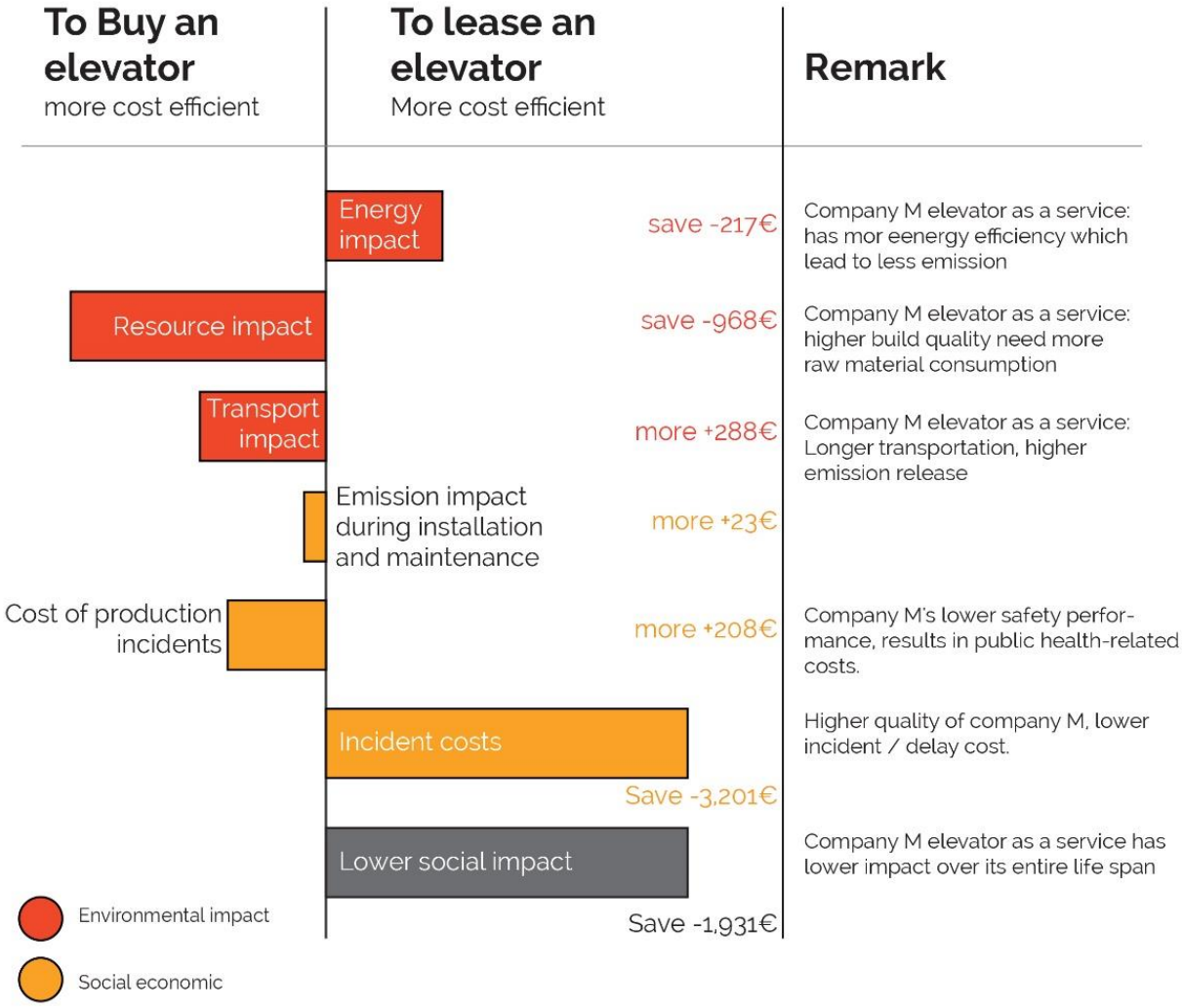

Figure 24: True cost of usage comparison (between company M elevator and buying conventional elevators),

“The elevator as a service model not only provides a high quality, long-lasting elevator with an entire lifetime repair and maintenance package (PSS consumers will use it as long as they wish to without any problem) but also offers financial advantages while using high-quality elevator” Said R.K. (personal communication, 2022)

PSS related aspect

This sub-chapter shows what the proposition offered by company M is and how it contributes to material leakage minimization.

Company M has been the top elevator as a PSS provider in Europe for many years. The main aim of company M which offer an elevator as a service is to provide a high-quality elevator with a longer life span, less burden (to both consumers and the environment), and greater financial benefit elevator to consumers (Company M related literature 1, 2020; R.K., personal communication, 2022). By doing so, company M could get benefit from supplying this by having a better position in the market, better company profit, and an opportunity to build up a close relationship with consumers (R.K., personal communication, 2022).

The provided feature of company M elevator as a service toward CE and material leakage minimization are included Smart sensors and intelligent systems, take back program, and a material passport.

1. Smart sensors and intelligent systems (technology)

   Company M applied smart sensors and intelligent software to investigate the actual information/ status of the elevator (how many times it is used in a certain period, how many minutes, and which part of the elevator is affected) in real-time. Therefore, Company M could provide proper and prompt maintenance according to each elevator's actual use. As a result, the elevator will last longer due to effective maintenance (Company M related literature 1, 2020). Over the last 7 years, elevator as a service of Company M has proven that technological development could greatly stimulate the circular economy model (Company M related literature 1, 2020).

2. Take back program

   The residual of the elevator (at the end of its contract) could be taken back to a company M manufacturer to be reused, recycled, or remanufactured. By doing this process, company M claims that fewer than 5% of the residual elevator waste is landfilled (Company M publication, n.d.). This not only reduces environmental impact by minimizing landfilled waste (material leakage) but also lessens consumers' burden in disposing of residual or broken elevator components.

3. Material passport (end-of-life management)

   Company M collaborated with a Dutch organization that could provide a material passport for the residual elevators' component (at the end of the contract), this enhances and facilitates the material recycling and reuse process (Company M related literature 1, 2020). This directly contributes to the material close loop as well as material leakage minimization.

4. Performance contract

   Pay-per-unit, or performance contract, this strategy not only ensures a provided product performance to consumers but also allows a provider to utilize resources more intensively. A combination of a take-back program, material passport, and performance contract contributes to closed material loops.

By offering these features, the PSS characteristics that induce material leakage minimization contributors are present in the elevator as a service which is provided by company M, namely

1. The proper product treatment by PSS providers

2. Delivering the product functionality using the most cost and resource-effective way by PSS providers

3. Support by specialized facilities and knowledge of PSS providers in PSS implementation

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Material leakage minimization-related aspect

To explore how the elevator as a service contributes to CE and material leakage minimization, the mentioned features of the elevator as a service are analyzed by using the PSS categories+two steps framework. Firstly, the provided elevator as a service feature is categorized according to Tukker's (2004) PSS category, to identify what category and what strategy of PSS the company M has offered. Thereafter, the investigation of how each provided PSS by company M contributes to CE, resource optimization, and material leakage minimization is conducted by using the two-step framework of Kjaer et al (2018). This could rationally illustrate what the consequences of implementing each provided PSS category and strategies are, and what is the result regarding the CE and material leakage minimization.

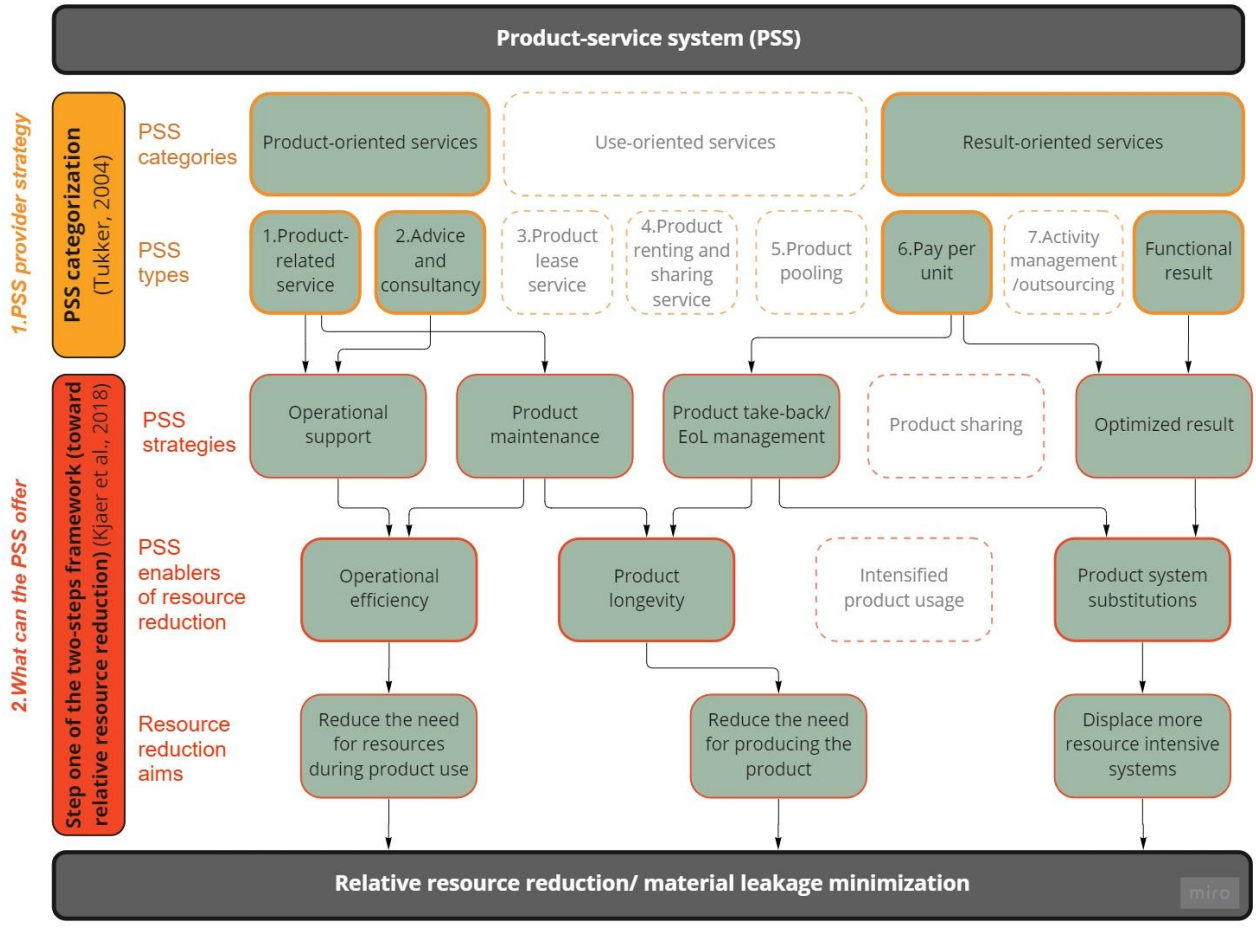

Figure 25: How could elevator as a service contribute to office material leakage minimization. Analyzed by using PSS categories+two-step framework, Source: Company M publication (n.d.), (Own illustration)

According to the provided feature of the elevator as a service, it could be described according to a PSS category+two-step framework that company M offers 2 PSS categories to its consumers, namely Product-oriented service and Result-oriented service. The green figures showed the aspects that are delivered by the company's M PSS.

Product-oriented service:

Company M installed an intelligent sensor in every elevator to investigate the functionality, elevator usage, performance, and stability of the elevator. The real-time information will deliver to Company M so that it can provide the best, most prompt, and accurate service/ maintenance for each consumer's elevators.

In addition, other products-oriented services such as advice, repair, reporting, and third-party inspection are also included in an elevator as a service package to facilitate the PSS consumer as well as contribute to the last longer product. Due to greater operational support and product maintenance of company M's elevator as a service, the elevator could be used more efficiently and last longer than others. Therefore, the need for resources during the use and production phase is reduced accordingly. Company M insisted that all PSS elevators will last longer than 40 years without having any burden on the consumer.

Result-oriented service:

In the elevator as a service model, PSS consumers only pay-per-use (pay per one vertical move) (Company M related literature 1, 2020). Company M always integrates performance contracts to the elevator as a service package to a consumer for quality/ performance assurance. In a pay-per-use or performance contract, consumers and company M agree on a result of product functionality, which is considered a result-oriented service PSS according to Tukker (2004). Therefore, these allow company M to utilize more circular elevator elements as long as delivering equal or better product quality and performance to consumers. Once the circular elements are more reutilized, fewer residual and broken elevator elements are disposed of (landfilled) or incinerated which leads to less material leakage.

Take-back program and material passport are important tools for company M for managing, recycling, remanufacturing, and utilizing residual elevator components and elements. By better managing residual elevator elements. Since the take-back program and material passport of the elevator as a service contribute to more re-utilizing elevator elements at the end of its life cycle, other elevators which are operating in the company M portfolio could last longer by using re-utilized components as spare parts for substitution of broken elements.

How does this provided PSS improve material leakage minimization? (material leakage assessment criteria)

As stated in the previous chapter, the four material leakage minimization contributors of PSS (Product life cycle extension, efficiency of resource utilization enhancement, higher waste recovery rate, and product circularity) could directly lead to material leakage reduction. The case study criteria are formulated according to these four contributors. A case study is to investigate how the PSS can provide an improvement to the office regarding material leakage minimization by using the four material leakage minimization contributors to compare the quantity and quality of material leakage minimization between the similar products that are provided by the linear economy and PSS.

According to the case study criteria, company M publication and the Head of sales of company M stated that its PSS strategy could mitigate the PSS on material leakage minimization contributors as shown in table 05.

	Material leakage minimization contributors			
Office components	**Component life span** (10yrs or lower = unsustainable)	**Component waste recovery rate** (50% or lower = unsustainable	**Product circularity** (Material composition and design for recycling)	**The efficiency of resource utilization** (strategy toward CE)
Conventional lift and conveyor (in general)	20+ years	-45%	- Electrical fitting/ lift/ mechanical/ Electricity	None (take-make-dispose)
Company M, Elevator as a service	40+ years	-98% (Resources are utilized more efficiently by using technology (an intelligent sensor) and circular facilities + online material passport)	- Same component, but more circular (design for disassembling) - Resources are designed to be more recyclable (material passport, take-back program) - Performance contract allows more flexibility in resource utilization	- End-of-life product management - Optimized result - Proper product maintenance - Proper operational supports

Table 05: (possible) improvement in 4 material leakage minimization contributors after replacing conventional elevator with company M elevator as a service, Source: Company M publication (n.d.), ABN Amro (n.d.), Lawrence et al (2010), CLF (2018), EPA (n.d.), Hardie (2011), (Own illustration).

After implementing PSS, Company M claims that 98% of the resource in the PSS portfolio could be re-utilized after the end of its life cycle (ABN Amro, n.d.). This means almost no material leakage is generated throughout company M's PSS life cycle.

Today the implementation of an elevator as a service helps company M achieve 6 out of 10R (reduce, reuse, recycle, etc.) of circularity. Company M is developing the elevator as a service toward achieving all of 10R in circularity.

Benefits and drawbacks of PSS (from a PSS providers point of view)

In addition to the material leakage minimization, the selected PSS provider also affirmed that various aspects could benefit PSS providers, consumers, and the environment by applying their PSS. The tables below represent the potential benefits and drawbacks of each selected PSS provider to the PSS providers (themselves), consumers, and the environment. In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

PSS provider		**PSS Consumer** (From what PSS provider experience)	
Advantages	**Disadvantages/ barrier**	**Advantages**	**Disadvantages/ barrier**
1. Opportunity to gain market share	Building law (building rights) is a barrier in some project Solution: elevator shaft (building attached element) have to be provided by a contractor, while the elevator car can be provided by company M	1. The cheaper total cost of ownership throughout the 30+ years (contract duration)	1. Too complex contract
2. High profit and long-term commitment to the consumer	2. Higher quality product = use more virgin material	2. Guarantee in using a high-performance elevator	2. Culture shift (of processing product)
3. Less resource consumption (contribute to a circular economy)	3. Long-distance product distribution (but can compensate with a lot lower resource consumption)	3. Less environmental impact (but it might be not the first objective for many consumers)	
4. Reduce environmental pressure			

Table 06: Benefit of M-use from the PSS providers perspective, Source: Company M publication (n.d.), R.K. personal communication (2022)(Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

R.K: "Yes, definitely. Due to high-quality elevators which last longer, Elevator as a service not only contributes to less material consumption, reduction of CO2 emissions but also a social contribution because there are fewer elevator confinements"

Summary

Company M is a famous elevator and escalator specialist company in Europe. It started providing elevators as a service in 2015 after company M collaborated with other parties for constructing a cradle-to-cradle-led office building in the Netherlands. After that, company M saw an opportunity to increase its market share by providing an elevator as a service model. Nowadays, the elevator as a service is considered the main source of income for company M.

For material leakage minimization-wise, material leakage from the consumer side is almost zero since all of the product responsibility is allocated to the provider (company M). Meanwhile, company M offers several features within the elevator as a service that contribute to material leakage minimization for their entire product life cycle.

The main features that company M provides with an elevator as a service are 1. Smart sensors and intelligent system: this optimizes efficiency in maintenance and repair by having real-time tracking of the elevator use. This leads to more product longevity. 2. Performance contract; which allows company M to flexibly use reutilized elevator products/ elements to fulfill consumer's needs, as long as the performance of product functionality remains or higher. This encourages company M to reuse, remanufacture, and recycle elevator components for being reutilized in the elevator as a service.3. Company M's PSS elevators are designed to be easily reutilized at the end of their life cycle. Material passport is also another important feature to manage those residual elevator products or components to be properly reutilized.

By doing so (reusing, recycling, and remanufacturing), the need for material extraction is lessened as well as disposal. With a combination of the provided features, material leakage is significantly reduced, and the product life cycle is extended. Therefore the waste recovery rate now is around 98%.

Case 2: Furniture as a service (Company A)

Company background and propositions offered by a provider

Company A is one of the largest office furniture companies in the Netherlands. It is providing office furniture and space solutions globally. Environmental sustainability is one of its main goals alongside creating vitalizing workspaces (Company a web page, n.d.)

Since the office furniture industry require a lot of virgin material and energy consumption, after a short period 80-90% of these resources are lost (Company A-related literature 1, n. d.). Therefore, company A has enthusiastically moved toward a circular economy and environmental impact reduction. Since the early 1990s, the strategies toward CE and environmental impact reduction of company A begins with production optimization such as using modular, disassembly furniture design as core principles. By doing this, partial repair, replacement, and upgrade of each product could be easily done (Company A-related literature 1, n. d.).

Thereafter, almost a decade ago, company A established a new business model, ” furniture as a service”. By proving this model, the ownership of the provided product (office furniture) remains at company A, while consumers could access product functionality through furniture subscription or furniture sharing platform. By doing so, company A could ensure that all of the provided furniture is correctly maintained during the use phase and correctly processed after the end of its life cycle (Company A-related literature 1, n. d.).

Company A invested more than 10 million euros in the upgrading of its furniture manufacturer, circular hub, reverse logistics, and development of a user-friendly online platform that allows a consumer to easily access company A products (S.P. personal communication, 2022). These are to best facilitate the furniture as a service model.

Easy accessibility (through an online platform), financial advantages, and flexibility are important factors of the FAAS model (Furniture as a service) to be chosen by the consumer, alongside furniture aesthetic and quality. Nowadays, FAAS is commonly used among major companies in the Netherlands such as Unilever, and Booking.com. Since they are big companies with a great number of employees, the investment in office furniture is tremendous. By using FAAS, they can allocate CAPEX to their main business and use office furniture by leasing as OPEX. Moreover, office furniture management is partially allocated to company A, there are fewer tasks for their CRE manager (S.P. personal communication, 2022).

By offering FAAS (furniture as a service), company A can earn high consistent profit from this model, which is can cover 10+ Euro of the initial investment (S.P. personal communication, 2022). Also, FAAS could allow company A to build a close relationship with the big company (consumers), which allow company M to increase its market share in office furniture as a service that results in higher company profit (S.P. personal communication, 2022). Moreover, a combination of furniture manufacture and the FAAS model could optimize material use and energy consumption during the manufacturing, use, and disposal phase, which might contribute to material leakage minimization.

PSS related aspect

According to the strategy toward CE and environmental impact reduction of Company A, it offers a full operational furniture lease with lifetime furniture repair and maintenance (unless defects are caused by misapplication) to the consumer via a user-friendly online platform. At the end of the leasing contract, company A provides three options for the consumer which are 1. Send them back to company A, then they can be re-utilized after being circularly processed in company A's" Circular hub" (a circular manufacturer). This is the most preferable way from company A. 2. Leasing contract extension, with a lower operational lease. 3. Consumers can buy it with a residual value of furniture, this is the least preferred option from company A (S.P. personal communication, 2022).

Company A offers four main features for FAAS to accomplish its strategy toward CE and environmental impact reduction namely, FAAS's user-friendly online platform, circular hub, and regular on-site inspection.

1. Furniture subscription (operational lease)

Company A offers furniture as a service, consumers can lease office furniture instead of buying it, the other service such as maintenance and repair are also included. Meanwhile, company A remains the owner of leased furniture. By doing so the furniture is treated properly and efficiently by company A.

2. FAAS user-friendly online platform

An online platform for consumers to access company A FAAS products portfolio to choose the most preferred office furniture which they want to lease, then the selected furniture is delivered to the consumers' door by company A (S.P. personal communication, 2022). In addition, the online platform is a communication channel between company A and consumers once consumers need an urgent repair, exchange, or return of their FAAS furniture. Each FAAS furniture comes with a QR code that indicates its identity (such as series, number, and contract length), therefore company A could promptly and efficiently manage and facilitate consumers' requests (Company A web page, n.d.).

3. Circular hub

A company A manufacturer that designs for supporting company strategy toward CE. A circular hub not only manages, recycling, and remanufacturing residual furniture (and furniture components) for being re-utilized again in the FAAS portfolio but is also a place to circularly modify the company A furniture to match particular consumers' needs by using a circular ingredient from company A furniture portfolio (S.P. personal communication, 2022).

4. On-site inspection

Every two years (of FAAS leasing contract duration), company A visits the consumer's place to observe whether the product is still in good condition to ensure their product functionality and aesthetics (Company A web page, n.d.). Thus, products are properly (partially or totally) repaired, maintained, and changed by an expert (Company A web page, n.d; S.P. personal communication, 2022).

By offering these features, the PSS characteristics that induce material leakage minimization contributors are present in the furniture as a service, namely

1. The proper product treatment by PSS providers

2. Delivering the product functionality using the most cost and resource-effective way by PSS providers

3. Support by specialized facilities and knowledge of PSS providers in PSS implementation

Material leakage minimization-related aspect

The three mentioned features of FAAS which are offered by company A could be classified as product-oriented service and use-oriented service by Tukker's (2004) PSS categories as seen in figure 26. The consequences of providing 2 PSS categories toward resource optimization and material leakage minimization (Circular economy objective) are investigated and then elaborated on a basis of the two-step framework of Kjaer et al (2018). Below, the yellow figures showed the aspects that are delivered by the company's A PSS.

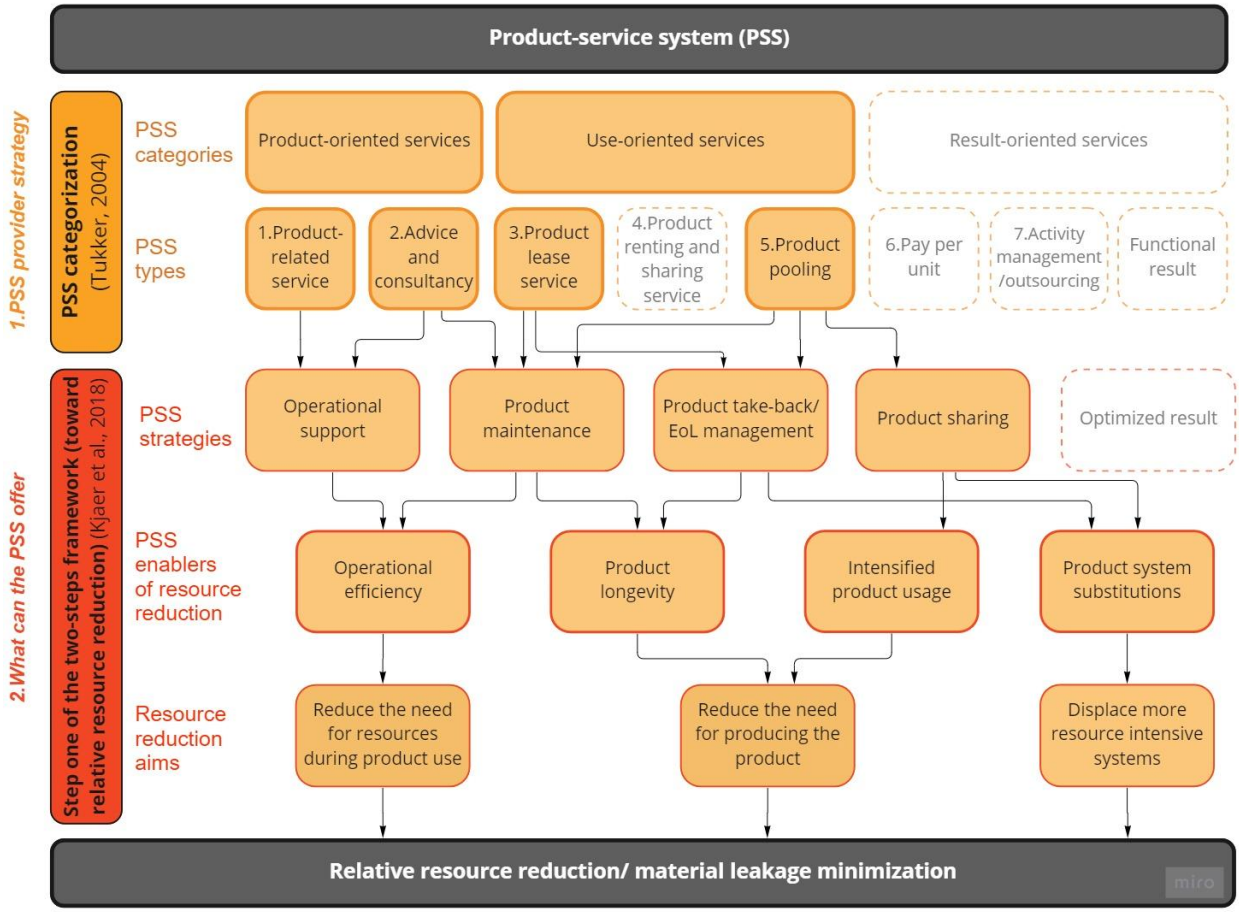

Figure 26: How could FAAS contribute to office material leakage minimization. Analyzed by using PSS categories+two-step framework, Source: Ahrend web page (n.d.); S.P., personal communication, 2022 (Own illustration)

Product-oriented service:

Company A has developed the FAAS online platform which allows consumers to easily access FAAS products remotely. This feature not only facilitates consumers' accessibility to FAAS products so that consumers can simply lease their preferred product but it is also a support channel for consumers who currently possess FAAS products through the attached QR code of each FAAS product

In addition, Company A manages an on-site visit to their FAAS consumers every two years to ensure their product functionality and aesthetics. Together with the attached QR of every FAAS product that allows their PSS consumers to reach company A at any time once there is any problem regarding their products, the products are properly maintained and repaired which leads

to increasing product durability and product life cycle extension by having proper maintenance and repair (if necessary) (Company A web page, n.d.). Consequently, the need for extracting resources and energy consumption in the use and production phase is reduced.

Use-oriented service:

Company A offers furniture subscription (operational lease) to its PSS consumers, therefore, the PSS consumers can access and select their preferred furniture from company A furniture online or sharing platform (furniture pool) (Company A web page, n.d.). After a certain period (minimum contract length is 2 years), the office furniture can be extended a leasing contract, exchanged, or returned to company A monthly, this provides a more flexible management option for the PSS consumers. In case the consumer chooses to return their FAAS furniture to company A, it is taken to a Circular Hub for being circularly processed (recycled, remanufactured) before returning to the company A FAAS portfolio again.

By doing this, the office furniture is more intensively used and properly/ effectively treated at the end of its product life cycle by company A which results in a reduction of the need for producing a new product. This contributes to a reduction of virgin resources and energy consumption.

How does this provided PSS improve material leakage minimization?

According to the case study material leakage minimization assessment criteria, company A stated in its publication that its PSS strategy could improve the 4 concerned material leakage contributions (product life span, waste recovery rate, product circularity, and The efficiency of resource utilization) as shown in table 07.

	Material leakage minimization contributors			
Office components	**Component life span** (10yrs or lower = unsustainable)	**Component waste recovery rate** (50% or lower = unsustainable	**Product circularity** (Material composition and design for recycling)	**The efficiency of resource utilization** (strategy toward CE)
Traditional office furniture	10 years	10-20%	Joinery/ timber hard/ workstation/	None (take-make-dispose)
Company A furniture as a service	Modular furniture (infinity) (more flexible up to 8-10 yrs)	58% recycle general waste 38% green/ grey energy production 4% waste	Less material is landfilled after more resource optimization, and permanent joints or glued joints are replaced with a modular structure.	-Proper operational support -Proper products maintenance -Product sharing -End-of-life product management

Table 07: (possible) improvement in 4 material leakage minimization contributors after replacing conventional office furniture with FAAS, Source: (Company A web page, n.d.; Company A-related literature Foundation, n.d.), Lawrence et al (2010), CLF (2018), EPA (n.d.), Hardie (2011) (Own illustration)

Since company A has been developing furniture as a service the circularity of the furniture as a service portfolio is getting better every year from 60% to 70% and nowadays it is over 80%+ (S.P. personal communication, 2022).

Benefits and drawbacks of selected PSS (from a PSS providers point of view)

In addition to the material leakage minimization, the selected PSS provider also affirmed that various aspects could benefit PSS providers, consumers, and the environment by applying their PSS. The table below represents the potential benefits and drawbacks of each selected PSS provider to the PSS providers (itself), and consumer. In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

PSS provider		**PSS consumer** (From what PSS provider experience)	
Advantages	**Disadvantages/ barrier**	**Advantages**	**Disadvantages/ barrier**
1. High profit	1. Furniture is easy to be damaged or destroyed (by consumers) during using period	1. Financial advantage (accomplish the scope without capital)	1. Too complex contract
2. Produce circular product	2. Expensive investment at the beginning (12 million Euro)	2. High flexibility in using a product (management/ financial aspect)	
3. A strong relationship with a consumer (big company)		3. Variety of services-user-friendly platform	
4. Environmental sustainability		4. CRE manager might not manage the office furniture	
		5. Environmental sustainability	

Table 08: Benefit of Ahrend from the PSS providers' perspective,
Source: Company A web page, (n.d).; Company A-related literature, (n.d.), (Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

P.S.: "Yes, first of all, products as a service have become more popular in many industries. People are adapting to a new way of leasing things. Meanwhile, the manufacturing development toward circular economy products these days, for example, company A products have been developing so far from the past. Nowadays, company A products are almost 100% renewable."

Summary

Company A, one of the largest Dutch office furniture manufacturers, has strived for reducing environmental impact as much as possible by producing modular, disassemble furniture which could extend the product life span. This results in resource and energy consumption optimization in the use and production phase of the provided furniture life cycle.

Furthermore, the business strategy of company A which provide office furniture as a service, product ownership remains at company A, while PSS consumer could use/ possess products through operational leasing, could optimize resource consumption, and minimize material leakage throughout the product life cycle (including at the end of its life cycle).

On one hand, since the ownership of FAAS products remains at company A, consumers are out of responsibility for product disposal after the end of the leasing contract. This means material leakage on the consumer's side is theoretically zero. On the other hand, a combination of a Circular hub, where the residual furniture components are circularly processed for being utilized as their second life, and an online platform could extend the product's life span by facilitating proper repair and maintenance of the product. This could reduce material leakage and resource consumption throughout the product's life cycle.

Nowadays, due to the developed aforementioned features of company A, the overall statistic of resource optimization and material leakage minimization of company A products are getting better every year. Now the circularity of furniture as a service portfolio is over 80% (S.P. personal communication, 2022).

Case 3: Circular carpet (Company I)

Company background and propositions offered by a PSS provider

Company I, an international specialized carpet tile manufacturer for commercial consumers was founded more than 50 years ago. In the last 30 years, the company became aware of the environmental impact, thus the company aimed to produce a product that has the least environmental impact (Company I-related literature 1, 2021). Since that time, a sustainable approach in product manufacturing has become company I's policy. Many goals, short-term, and long term were practically set by the company I to make it becomes the pioneer company that provides carbon-neutral products.

By having a great reputation for providing environmental sustainability products from proving to the world that providing environmental sustainability products is feasible, the company I have been got enormous attention from many companies (consumers) worldwide, according to the "environmentally friendly" as a current global trend (J.L., personal communication, 2022). This becomes a company I selling point that brings about possessing a huge market share and earning a great amount of income.

Since providing circular and carbon-neutral products has become one of the priority objectives of company I, many strategies and product features have been developed. The first two highlight features in product manufacturing are using 100% of recycled or bio-sourced material for producing products (carpets) since it generates a 35% lower carbon footprint compared to the one that is produced from other virgin materials (Company I-related literature 2, 2021). Also, circular carpet is provided as a modular and removable design which could enhance product flexibility (if some modules are damaged they are taken back for being recycled and remanufactured at the company I factory, consumers do not need to change the entire carpet) (Company I-related literature 1, 2021). By doing this, product maintenance and repair are optimized, and the unnecessary disposal of materials is reduced. The company I also trains their consumer to ensure products are looked after correctly which leads to more product durability. Once consumers no longer want company I circular carpets, they could be sold to a company I through the buy-back guarantee option. This not only diminishes the consumer's burden on carpet disposal but the company I could obtain resources to be re-processed for producing new circular carpets.

Even though the company I has not provided carpet as a service or high level of service PSS categories such as use-oriented service and result-oriented service, according to Tukker's (2004) PSS categories model, it has delivered a great efficient product-oriented so far. A company I see that some uncertainties have to be more studied before implementing other PSS categories. One example of a company I for not yet providing carpet as a service is that some consumers think that carpet as a service is not financially worthy (J.L. personal communication, 2022).

Nowadays, a company I is considered a highly successful company in providing an environmentally friendly product. Countless of major corporates, hotels, or housing projects (consumers) currently use a company I's product worldwide. Nevertheless, a company I will not stop developing its strategy toward carbon neutrality and environmental sustainability in this state, although it is considered highly successful in what company I has developed (J.L. personal communication, 2022). Soon, company I is planning to offer a carpet subscription called "Tile Exchange" or tile pool (Company I-related literature 2, 2021). In addition, the reverse logistics of a company I required development to optimize circular carpet production which could lead to an opportunity for increasing circularity in a company I portfolio (J.L., personal communication, 2022).

PSS related aspect

Other than the aesthetic wise of carpet, a company I has been striving for providing and producing circular and carbon-neutral carpet, much research and design are done to achieve its objectives. The below strategies are how the company I practically pursue its objective of producing circular and carbon-neutral carpets.

1. Using fully recycled and bio-source material.

A reduction in using synthetic material which is non-biodegradable and non-recyclable materials is the main strategy for closing material loops. According to Company I-related literature 2 (2021), using fully recycled material in carpet production generate 35% less carbon footprint compared to one that is made of virgin material.

Nowadays, the company I is using fully recycled fabric/ fiber to produce the new carpet. The take-back or buy-back guarantee approach plays an important role in facilitating circular carpet production by reclaiming unwanted carpets (fabric) before being recycled or remanufacturing them in the company I factory. The process of reutilizing material is done according to the EU waste hierarchy model (such as keep reusing it first then recycling it).

Introducing bio-sourced material in carpet manufacturing not only lowers environmental impact but also helps to capture carbon (Company I-related literature 1, 2021). In the past, there was one major circular-wise weakness in the company I carpet manufacturing which was the backing of every carpet is a synthetic material, a “bitumen”, which is petrochemical. This make recycle become more difficult. Since 2015, bitumen backing was replaced by bio-based backing which is fully recyclable (J.L., personal communication, 2022). As a result, now the company I portfolio circularity has increased to almost 90% J.L., personal communication, 2022). Products (carpets) and product components can be more effectively reutilized.

2. Modular carpet

The company I offer modular and removable carpet tile which increases product flexibility since it can be more efficiently repaired, removed, and maintained. Once the carpet is damaged, only the damaged parts are repaired and replaced while the rest is remained untouched.

3. Buyback guarantee/ carpet takeback

The take-back or buy-back guarantee option allows PSS consumers to sell carpet back to the company I with residual value after they no longer want it. The unwanted carpet is recycled and remanufactured at the company I factory for producing new carpet. The buy-back option is also viable for buying a residual carpet from another manufacturer (another carpet brand). This action of the company I contribute to the closing material loop (for carpet)

4. Customer training

This approach is to ensure product durability by having proper product maintenance by the PSS consumer. Therefore, both consumer and provider could get benefit from an extended product life span.

By offering these features, the PSS characteristics that induce material leakage minimization contributors are present, namely

1. The proper product treatment by PSS providers

2. Delivering the product functionality using the most cost and resource-effective way by PSS providers

3. Support by specialized facilities and knowledge of PSS providers in PSS implementation

In the beginning, the consumer might not directly benefit from the most cost and resource-effective in using circular carpet. However, the buyback guarantee/ carpet take-back feature can be beneficial to consumers and company I (PSS provider) once the circular carpet is no longer needed by the consumers.

Material leakage minimization-related aspect

The provided features of a company I are categorized as product-oriented services according to Tukker (2004). The other feature to achieve CE is developing but has not yet been implemented such as carpet subscription. Even though there is only one provided PSS category, the company I has been highly successful in delivering circular products since the circularity in the company portfolio is almost 90% (.J. L., personal communication, 2022). The light green figures showed the aspects that are delivered by the company's I PSS.

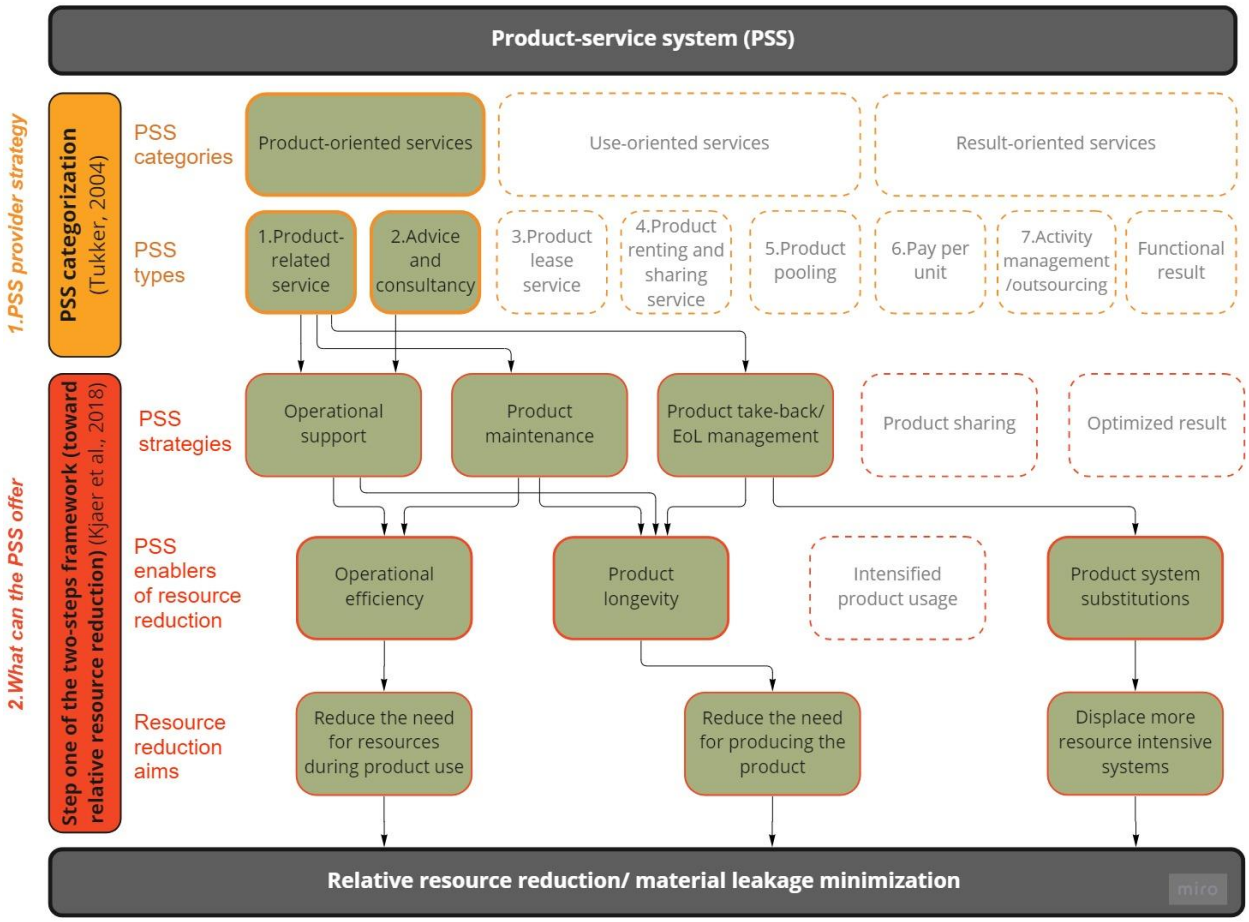

Figure 27: How could Interface carpet contributes to office material leakage minimization,
Source: Company I-related literature 1 (2021); Company I-related literature 2 (2021); J.L., personal communication (2022), (Own illustration)

Product-oriented service:

The company I always trains the consumers to take care of the carpet correctly. Doing this could lead to more product durability and the product being used more effectively (Company I-related literature 1, 2021). Therefore, during the use phase, the need for product resources is reduced since the products last longer.

Carpet tiles (a company I's products) are delivered as modules that are easy to be partially removed, repaired, and maintained. This enhances product flexibility which could lead to a rise in operational efficiency, less usable materials being landfilled, and the overall product lasting longer. Therefore, the need for resource consumption during the use and production phase is reduced.

A prime strategy toward CE of company I is shifting its production principle to use fully recycled and bio-source material. This not only presents company I as an example company that can prove to provide an environmentally friendly product is possible but the company I also gain market share in selling a circular product (J. L., personal communication, 2022). Another feature that compliments circular carpet production is the carpet take back or buy back guarantee, this feature allows company I to reclaim residual/ unwanted carpets which are produced by the company I or another manufacturer to be reprocessed before being used as material in producing new carpets in the company I factory. Moreover, recycled carpet could be used as a spare (modular) carpet for the carpet which is currently used, as to be partially replaced a damaged module. Partially repairing and replacing the carpet modular could help the overall (currently using) carpet last longer (without being entirely changed).

As a result, the material is used more intensively so less material leakage is generated in the carpet industry. This contributes to a closed-loop material.

How does this provided PSS improve material leakage minimization?

According to the material leakage minimization assessment criteria, the company I stated in its publication that its circular strategy could improve the material leakage minimization contributors table 09.

	Material leakage minimization contributors			
Office components	**Component life span** (10yrs or lower = unsustainable)	**Component waste recovery rate** (50% or lower = unsustainable	**Product circularity** (Material composition and design for recycling)	**The efficiency of resource utilization** (strategy toward CE)
Traditional carpet/ flooring	5-15 years	3%	Carpet	None (take-make-dispose)
Company I carpet	15-30 Years (Flexible as it is a modular carpet)	Almost 100% recyclable	-Using fully recyclable and bio-sourced materials. -Replacing bitumen backing with bio-based backing.	-Proper operational support -Proper products maintenance -End-of-life product management

Table 09: (possible)) improvement in 4 material leakage minimization contributors after replacing conventional office carpet with a company I, Source: (Company I-related literature 1., 2021; Company I-related literature 2, 2021), Lawrence et al (2010), CLF (2018), EPA (n.d.), Hardie (2011 (Own illustration)

A company I have been developing a circular carpet for many decades. Nowadays the circularity of the circular carpet portfolio is up to 90%. Almost the entire residual carpet is fully recyclable. Since almost carpet is made from circular material, it has 35% less carbon footprint compared to one that is made from virgin materials (Company I-related literature 2, 2021).

Benefits and drawbacks of selected PSS (from PSS providers' point of view)

In addition to the material leakage minimization, the selected PSS provider also affirmed that various aspects could benefit PSS providers, consumers, and the environment by applying their PSS. The tables below represent the potential benefits and drawbacks of each selected PSS provider to the PSS providers (itself), consumer, and environment. In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

PSS provider		**PSS consumer** (From what PSS provider experience)	
Advantages	**Disadvantages/ barrier**	**Advantages**	**Disadvantages/ barrier**
1. Produce a circular product and proof that providing a completely circular product is possible	1. An improvement in reverse logistics is needed.	1. Increase circularity in the consumer portfolio	N/A
2. Increase market share by providing a circular product (gain profit)	2. More collaboration among project parties is needed to push CE strategy to the next level	2. Have an opportunity to sell the carpet back to the company I (less disposed material by a consumer)	
		3. Flexibility in using and arranging products in consumers' portfolio	
		4. Customer training could guide a consumer to look after the carpet properly	

Table 10: (possible) change in 3 attributes after replacing conventional office carpet with Interface, Source: (Company I-related literature 1., 2021; Company I-related literature 2, 2021), (Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

J.L.: "Yes, I think it is a valuable model. If you do this model well, you connect with people that maintain this product and you have joint responsibility. Even though it requires collaboration between every party, but if all of their though are aligned toward environmental sustainability and they all really want to push it, I think it works"

Summary

A company I is an international well-known carpet manufacturing company that has a strong ambition toward environmental sustainability. The company has put its effort into R&D on the production process to produce the fully circular carpet. This is a selling point of the company I. Most of the company I circular approaches are categorized as product-oriented service according to Tukker's (2004) PSS categories model, while the other PSS categories such as use-oriented and result-oriented services are in the developing process. Even so, the company I is considered a high success in providing the circular product.

Its main feature is using recyclable and bio-source materials to produce carpets. Meanwhile, the take-back or buy-back guarantee program is for reclaiming the residual carpet from the consumers to be processed (according to the EU waste hierarchy model) at the company I factory before reutilizing them as material for producing new carpets. Customer training and delivering carpets as modular also improve product life span, and operational efficiency by having more product flexibility and proper maintenance.

Since circular carpet is still provided as a product-oriented service, product responsibility is allocated to a consumer after purchasing. However, buy back option could help a consumer to get rid of product disposal at the end of the carpet life cycle and close the material loop. Therefore, the material leakage from the consumer side is reduced.

As reported by Corvellec and Stal (2017), the amount of waste that is generated during the implementation of PSS does not depend on the provided PSS categories but it relies on the material flow and resource utilization. The case of the company I prove that the finding of Corvellec and Stal (2017) is true by providing the least service PSS categories (product-oriented) while having an amazingly 90% of product portfolio circularity.

4.1.2 Individual case and analysis of PSS consumer (demand side)

Case 4: Fast fashion shopping store (Company P)

Company background and its using office component PSS

Company P is a newly emerged Asian fast-fashion online store. It was founded in 2013, a company P's headquarter is located in Bangkok, Thailand. Even though company P's main business is driven through an online shopping platform, physical stores are necessary components in running its business. The physical store is a place to connect consumers with company P's products where PSS consumers can touch, feel, and try fast-fashion products firsthand (K.A., Pomelo store development, and designer, personal communication, 2022).

As a new fashion brand in the market, company P needs to create its brand identity to make the brand recognizable to its PSS consumer as a marketing campaign. One suitable place to promote its brand identity is in its physical shopping stores which are distributed around Southeast Asia. Three PSSs are used at the company P shopping store are followed.

1. **Ambient odor as a service**: An ambient odor service to create a scent of the brand. By doing so, the customer could recognize company P's brand identity through an ambient odor in its physical shopping store.

2. **Music playlist as a service**: A playlist PSS provider that provides suitable music playlists for each retail. This could also create an engagement of customers through company P's retail background music.

3. **Smart locker**: Company P hires a PSS provider to distribute the lockers with a smart system throughout the major cities in Southeast Asia. Company P uses this locker as a channel to connect with customers by allowing a customer to pick up and return their ordered products to company P via distributed smart lockers. This locker facilitates company P's marketing campaign called "Omni-channel" which is an effective combination of online and physical shopping.

Material leakage minimization by using PSS

Material leakage minimization by PSS is not the main driver of company P applying PSS in the shopping store. Also, material leakage is generally less concern in Thailand since there is no material scarcity there and environmental regulation there is not yet strict (K.A., Pomelo store development, and designer, personal communication, 2022).

In company P's shopping store, all PSS product ownership that company P uses remains at the PSS provider, therefore company P does not responsible throughout the PSS product's life cycle. By doing so, material leakage which is responsible by company P during the use phase and company P's place transformation is theoretically zero.

Even though material leakage minimization is not the main driver for company P to use PSS, material leakage minimization by using PSS could result in several benefits for company P. Material leakage minimization by using PSS could help company P to lower the company expense

during refurbishment, relocation, and resizing of the shopping store which occurs multiple times each year. Since finances is a priority aspect for a newly established company like company P, avoiding additional costs, such as demolition costs, and disposal fees, in each retail refurbishment is essential. Also, material leakage minimization by using PSS can indirectly influence company P by promoting the brand image as an environmentally friendly brand.

Benefits and drawbacks of using selected PSS (from a consumer point of view)

In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

Consumer	
Advantages	**Disadvantages**
1. Using PSS can facilitate company P's brand identity and company strategy enhancement	1. Feasibility (if the service is too expensive, company P will not use it)
2. Learning from experts (PSS providers) and knowledge exchanging; could help company P to improve the brand	2. Some PSS requires a long-term commitment, but the company's P branding is often re-branded, therefore it is difficult to manage a long-term commitment PSS
3. Fewer problems with the maintenance and repair while using PSS product	3. Complexity of contract
4. Always access to the latest technology/ upgraded products	
5. Environmental sustainability (good for company P's brand image)	
6. The flexibility in using PSS product	

Table 11: Benefits and drawbacks of using selected PSS (from a consumer point of view) (K.A., Company P store development, and designer, personal communication, 2022)(Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

K.A.: "Yes…..nowadays more and more people understand and get used to product/ service subscription. Soon, product or service ownership will no longer matter to consumers. Since most product or service remains to PSS providers, it allows PSS providers to optimize resource utilization."

Summary

Company P is a new Asian fast-fashion brand that develops an online platform as the main channel for marketing and selling its products to consumers, located in Bangkok, Thailand. However, the physical shopping store is necessary as it is a place where customers can touch, feel, and try fast-fashion products firsthand.

The store manager and designer of company P see that it is a great opportunity to represent company P's brand identity and create an engagement with a customer through the physical shopping store. Therefore, company P applies the three mentioned PSSs to its shopping store in order to enhance brand identity.

Although material leakage and environmental pressure minimization are not the main drivers for company P to use PSS, it generates benefits for company P.

Case 5: Hi-technology manufacturer (Company V)

Company background and its using office component PSS

Company V is a Dutch large manufacturer that runs many businesses such as car manufacture, high-tech supply, production and sale of buses, and plastic processing that was established 70 years ago. Company V has been running as a family business that manages with old fashion business mindset. Company V's major assets (real estate and manufacturing facilities) are always possessed by traditional purchasing since company V always wants to own everything itself. Managing major assets of company V is a long-term plan, the owner and board of company v believe that it is easier to possess them through traditional purchasing (M.B., personal communication, 2022).

Leasing and renting major assets have not been an option for company V. The owner and company V board think that owing by purchasing (mostly using cash) and if they no longer want it just selling it for a sum of money at once is an easier and more convenient option. From their point of view, leasing (or PSS) always comes with a complex contract, and calculating and trying to balance the operational lease every month is too complicated (M.B., personal communication, 2022). Leasing only applies for having or using small equipment such as a copy machine since it is more convenient as everything is included (service, maintenance, etc.) (M.B., personal communication, 2022).

A change in the real estate portfolio depends on the need for the expansion of the real estate (building or facility) to facilitate the main company V business. Almost all transformations of its real estate are done through traditional purchasing. Once the real estate or manufacturing facilities of company V are no longer used, company V mostly sells the whole building (sometimes including huge machinery) to the market. Then it uses this money as capital for future real estate portfolio transformation (M.B., personal communication, 2022).

Material leakage minimization and benefit of company V by using PSS

Material leakage is a concern but it is not the main issue for company V. Nevertheless, it is trying to optimize its resource during the transformation of its facilities. Company V not only has old fashion mindset in doing business but also in building and renovating its corporate real estate. Most of its building is constructed traditionally by having concrete and steel which has a high recovery rate after demolition as the main construction material. Concrete and steel in its corporate real estate after transformation and demolition mostly be reused at the other company V corporate real estate construction site.

Only a few small pieces of equipment in company V are possessed by PSS. Company V sees that the top benefit of using PSS is that everything is included (service, maintenance, etc.) which is more convenient since company V can access those products' functionality without product responsibility. Meanwhile, the other benefits (other than material leakage minimization) of using PSS are not yet aware by company V. The majority benefit of using PSS such as financial advantages is not a concern for company V since the corporate real estate of company V is operated with old fashion mindset. Company V always has enough budget (capital) for purchasing or expanding corporate real estate.

Since company V hardly uses PSS and never uses PSS in the building layer, it thinks that material leakage minimization by using PSS is a relatively very small amount and is usually not in consideration. Material leakage minimization is not the main driver for company V to use PSS.

Benefits and drawbacks of using selected PSS (from a consumer point of view)

In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

Consumer	
Advantages	**Disadvantages**
1. Using or possessing products without products responsibility	1. Complexity of contract
	2. Not comply with company V's real estate management mindset

Table 12: Benefits and drawbacks of using selected PSS (from a consumer point of view) (M.B., personal communication, 2022)(Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

M.B.: "Yes.. I think there is a high possibility"

Summary

Company v is an old large Dutch mechanic and hi-tech manufacturer. The company's real estate has been managed with an old fashion mindset that possesses all major assets by traditional purchasing (mostly using cash). There is no leasing option for company V's major assets. PSS that company V is currently using is only small office equipment such as copy machines.

Material leakage minimization is not the main objective for company V corporate real estate management, but it is still a concern. The improvement of material leakage minimization by using PSS is hardly noticed by company V since company V has never used PSS for its corporate real estate or manufacturing facilities which generate most of the material leakage.

Even though company V only uses small office equipment PSS, it realizes the benefit of using PSS. Using PSS is convenient for company V since the responsibility of the product remains with the PSS provider, company V could use and possess PSS products with less burden. Material leakage from using PSS products is principally zero on the consumer side.

Case 6: University in the Netherlands (University E)

Company background and its using office component PSS

University E is the top 5 best universities in the Netherlands and among the top 150 of the world's best universities (QS World University Rankings, 2022). University E was established around mid 19th. The corporate real estate of the university E is considered an immense area, 300,000 sq.m. which includes university facilities, a sports complex, student housing, etc. (D. P. and S.H., personal communication, 2022). Most of the university E real estate transformations are renovation and relocation.

BREEAM is being used as a standard for environmental sustainability in managing university E real estate. The current focus on environmental sustainability is to optimize the heating and cooling system in the building and minimize of using gas (D. P. and S.H., personal communication, 2022). Material leakage during real estate transformation is also one of concern. The residual component and materials of university E corporate real estate are well managed to be reused after its real estate transformation takes place by applying a material passport and hiring a circular demolition contractor (third party) to properly manage residual building material while demolishing or renovating the real estate of university E. Material passport is another important tool to manage residual building material. By doing so, around 70% of residual building material of university E real estate after transformation is reused for another new construction on the campus.

Less than 30% of residual building material is discarded, which is material leakage. Most of the discarded material is polluted or toxic material from renovating or demolishing antique or historical buildings in the campus for example a dome building. Most of the polluted materials are old paint and asbestos.

In the university E corporate real estate portfolio, a building layer PSS has never been used as it is very difficult in the Netherlands due to the building layer PSS implementation barriers namely building ownership regulation, the financial structure of the university E, and building construction management. Most of the PSS that university E uses is a service layer (stuff) according to Pushkar (2015) which has been commonly leased in the market for a long time. Coffee machines, vendor machines, copy machines, and office furniture are PSS that is commonly used on the campus of university E.

Material leakage minimization and benefit of university E by using PSS

Material leakage for currently used PSSs is considered a relatively little amount since they are small equipment such as coffee machines, copy machines, and office furniture. The majority of material leakage in university E real estate is building components. Therefore, nowadays those currently used PSS is not significantly improved material leakage minimization of the university E real estate.

From a point of view of the university E real estate manager, a PSS is a good idea to minimize material leakage by using PSS for major assets like building components, which generates more material leakage during office or real estate transformation. However, the university E real estate department has never had experience using PSS for major components (building layer) due to the building layer PSS implementation barriers. The real estate manager and strategy & consultancy manager of university E believe that using PSS for major components (building layer)

is a good solution to minimize material leakage in university E's real estate transformation in the future once the building layer PSS implementation barriers are overcome.

Benefits and drawbacks of using selected PSS (from a consumer point of view)

In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

Consumer	
Advantages	**Disadvantages**
1. Enhance the circularity of the real estate portfolio	1. Not applicable for university E financial structure (for building layer PSS)
2. More convenience in taking care of the product	2. Not comply with Dutch building ownership regulation (for building layer PSS)
	3. Complicated management of the portfolio, more parties are in the project

Table 13: Benefits and drawbacks of using selected PSS (from a consumer point of view) (D. P. and S.H., personal communication, 2022)(Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

S.H.: "Yes.. I think it is a fundamentally good idea to minimize material leakage by using PSS, but it might take some time to implement PSS for building layer components since the current barriers in implementing need to be overcome first "

Summary

University E is a famous university in the Netherlands. Its real estate portfolio is accounted for 300,000 sq.m. which includes university facilities and other accommodations for staff and students. Environmental sustainability is highly concerned with managing the university E real estate portfolio to minimize the environmental impact that is generated during the university E real estate transformation. BREEAM is used as an environmental sustainability standard for university E real estate.

Material leakage is highly concerned in the university E real estate management. Hiring a circular demolition contractor (third party) to demolish its building once its real estate portfolio is changed in order to organize residual building material or components for being reused and applying a material passport are primary strategies to minimize material leakage during real estate transformation. The current material leakage from real estate transformation is 30%, and most of them are toxic and unreusable residual construction materials such as chemical paint or asbestos.

Most of the PSSs that are currently used are small office equipment such as coffee machines, copy machines, and office furniture which are considered basic leasing items for a long time. Current used PSSs of university E do not mean to minimize material leakage in a real estate transformation since most of the material leakage is residual construction materials.

However, both the university E real estate manager and strategy & consultancy manager believe that in principle PSS is a practically good idea to minimize material leakage in real estate transformation soon. Nowadays, the result of material leakage minimization in the construction industry has not yet been obvious since only a few PSS in building layers are limited in the market due the implementation barriers. University E is eager to apply PSS for the building layer in the future.

4.1.3 Individual case and analysis of other PSS-related professionals

Case 7: knowledge organization for leasing professionals in the Netherlands (Company L)

Company background

Company L is a knowledge organization for leasing professionals and a representative of a company that provides leasing products in the Netherlands. Company V was founded in 1972. Company V is focusing on a wide range of business assets leasing such as trucks, machinery, industrial equipment, copy machine, and IT solutions.

Current situation of using PSS in an office from a company L field of knowledge

According to personal communication with P.B. managing investor of Company L in 2022, leasing assets for business in the Netherlands has been developing for many last decades. Most common leased products are stand-alone or movable objects. In contrast, a building layer component or any product that attaches to the building has been a rare case for being provided as a leased product in the market. From the managing investor of Company L's point of view, three main barriers that inhibit the implementation of leasing building layer components are the financial aspect, the complexity of construction management, and Dutch building ownership regulation (P.B., personal communication, 2022).

Once consumers want to lease building layer components for developing their real estate project they need to finance it themselves as those components are not considered a part of their assets and most banks might not approve a loan for leasing those components. Also, approving a loan for leasing building layer components is risky for the bank (financial provider) as the residual value of the component is difficult to calculate since they are attached to the building, and most of them might be minus (demolition cost, remanufacture cost, transportation cost are needed). Since the PSS products ownership remains with the PSS providers, a bank has to evaluate the financial risk of the consumer (building owner), the consumer’s project, and the product provider before approving a loan. This is excessive work for a bank for approving a loan for only one project, thus no bank is willing to do that (P.B., personal communication, 2022).

A complexity of construction management, once the building layer components are procured as leasing products, the project consortium becomes more complicated as a product provider has to participate in the consortium (the leased product ownership remains to the product provider). A Dutch regulation is also a hindrance to implementing leasing a building layer component. The building right and accession in Dutch law do not allow everything that is permanently attached to the building to be owned by a third party (provider) (Parker, 2021; Zwart, 2020; P.B., personal communication, 2022).

From P.B.'s perspective, nowadays only stand-alone or movable products are feasible to be provided as leasing products while building layer components of building attached products have not yet ready due to the aforementioned barriers. However, he still believes that the strategy of providing building layer components as a leasing product has been developed so far, and it could be feasible shortly (P.B., personal communication, 2022).

Material leakage minimization and benefit of using PSS from a company L field of knowledge

The environmental sustainability approach is essential nowadays. Circular materials/ products are obliged to be more in the EU due to the EU circular economy plan and scarcity of raw materials. It could cause a great opportunity for the project such as an incentive for being a sustainable project. Also, many banks these days only approve a loan for a project that reaches an environmental sustainability standard (P.B., personal communication, 2022).

Since the PSS provider remains the owner of products, they have been developing strategies to get the best benefit from providing products as a service. Optimizing the product to reach its maximum working capacity and using fewer resources in providing the same product functionality and quality are the primary objectives for PSS providers. As s result, material leakage is minimized (P.B., personal communication, 2022).

Benefits and drawbacks of using selected PSS (from other PSS-related professionals' points of view)

In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

Other PSS-related professionals	
Advantages	**Disadvantages**
1. Optimize both provider and consumer financial plans	1. For the bank (financial supporter), it is difficult to evaluate the residual value of some PSS products, therefore it might not approve a loan for implementing some PSS.
2. Easier to get a loan/ mortgage for an environmentally friendly project (incentive for being environmentally friendly).	2. More expensive PSS = more risk (financial risk)
3. Reduce material scarcity	3. Building layer components PSS implementation barrier needs to be overcome

Table 14: Benefits and drawbacks of using selected PSS (from a consumer point of view) (P.B., personal communication, 2022)(Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

P.B.: Yes, definitely. Human is always trying to be creative, to think about a new strategy to earn benefit by developing a new strategy or optimizing what they have done in providing PSS. Having less material leakage is also one thing that is being developed.

Summary

Company L is a knowledge organization for leasing professionals and a representative of a company that provides leasing products in the Netherlands. From its field of knowledge, stand-alone or movable products are commonly provided as leased products. While leasing building layer components or any products that attach to the building is very limited in the market as there are barriers to implementing them.

Nevertheless, P.B. thinks that PSS is a good model to minimize material leakage as the PSS provider has to optimize product working capacity and resource consumption for getting the best benefit from providing the product as a service. Once the implementation barrier of leasing building layer components is overcome, PSS for building layer components might become the prevailing model in the market as it complies with the environmental sustainability trend.

Case 8: Furniture design company in Thailand (Company T)

Company background

Company T was founded in Bangkok Thailand by a new generation of furniture designers. V.C. is a designer and owner of company T who has been working in the furniture and product design industry in Thailand for many years. Most of the company T product is outdoor and office furniture which emphasize aesthetic and ergonomic design. Since V.C. is also designing furniture himself, he knows every state of the furniture life cycle that is produced in Thailand. He is also interested in PSS and trying to apply it for developing his business in the future.

Current situation of using PSS in an office from a company T field of knowledge

Even though office furniture PSS in European countries is prevailing, In developing countries like Thailand office furniture PSS is not commonly used. As mentioned earlier, circular economy and environmental sustainability are less concern in Thailand due to weak environmental regulation and no resource scarcity.

Since labor and material cost in making furniture is cheap in Thailand, a consumer often opts to possess furniture by traditional purchasing and dispose it of if it is no longer wanted. Doing this is often cheaper and less complicated in possessing furniture in Thailand compare to using PSS furniture (V.C., personal communication, 2022). Furniture handymen in Thailand have great skills with cheap labor costs, hiring them to fix, modify, and upgrade furniture is a more efficient way to service them compare to using PSS furniture.

In Thailand, almost all PSS furniture occurs only in business-to-business operations. Organizing a temporary event is the most common use of PSS furniture such as leasing furniture for a couple of days to organize a wedding ceremony. A short-term furniture PSS is commonly used, while a longer-term furniture PSS model has not yet succeeded in the Thai market. In the longer term of possessing furniture, owning by traditional purchasing and then hiring a furniture handyman to fix or upgrade it if needed is cheaper and it is a more prevalent way in Thailand.

Material leakage minimization and benefit of using PSS from a company T field of knowledge

Environmental sustainability and circular economy are not the main purposes of a consumer in choosing furniture in Thailand. However, many furniture companies in Thailand are offering environmentally friendly products as their marketing strategy.

Currently, some Thai furniture companies initiate offering their consumer a take-back program, which allows their consumers to bring an unwanted or old product that was bought from them back for exchanging or getting a discount when the consumers want to buy new furniture from them in the future. Then most of the taken-back furniture is modified or remanufactured in the factory before being sold again. Steel and wood which are the main material of their furniture are simply re-utilized, by doing so the need of extracting virgin resources is reduced. Even though the take-back program means to increase company sales, minimizing resource consumption and material leakage of the office furniture in producing and disposal phase are also a consequence of providing the take-back program.

Flexibility and convenience are the main drivers for a PSS consumer in using PSSs furniture that is provided as a short-term service (for organizing an event) in Thailand. Apart from the mentioned advantages using short-term PSS furniture could lead to less burden and material leakage for the consumer after using it.

Benefits and drawbacks of using selected PSS (from other PSS-related professionals' points of view)

In the below table, the benefits and drawbacks are prioritized in order according to the interviewee's concerns. 1 is the most concerning benefit or drawback of implementing PSS, while the higher number the less concern it is.

Other PSS-related professionals	
Advantages	**Disadvantages**
1. Enhance business opportunities/ increase company market share	1. PSS might not be feasible in some country where labor and material cost is low.
2. Developing providers/consumers' relationship	2. SMEs are unaffordable to provide PSS
3. Circular economy contribution (closed-loop)	3. Require a cultural shift in owing products
4. Increase product use flexibility	4. Contract complexity

Table 15: Benefits and drawbacks of using selected PSS (from a consumer point of view) (V.C., personal communication, 2022)(Own illustration)

Is PSS an effective strategy to minimize material leakage? (opinion of interviewee)

T.Sommitr: "From your point of view, could PSS be an effective strategy to minimize material leakage?"

V.C.: "Yes, for sure! Material leakage is always a consequence of providing/ using PSS for both consumers and PSS providers. It is a good solution for minimizing material leakage if you can implement it. However, nowadays, a major challenge is how to implement it, how to overcome those barriers, and how to make this become one of the prevalent procurement options"

Summary

Company T is a Thai new-generation furniture design company. Most of the company T product is outdoor and office furniture which emphasize aesthetic and ergonomic design. V.C is a designer and owner of company T who is interested in applying the PSS model to develop his furniture company.

In developing countries like Thailand, environmental sustainability and a circular economy are not the main concerns in the Thai furniture industry due to weak environmental regulation and no resource scarcity. Also, cheap labor costs affect the price of the furniture to become cheaper. Cheaper furniture prices simply enable a PSS consumer to buy and dispose of the furniture when it is no longer wanted, more complex procurement as PSS (or leasing) has not yet been commonly used.

PSS in the furniture industry in Thailand mostly carries out business-to-business or for a very short-term (leasing) service such as leasing furniture for one or two days to organize a special event. Some of

Even though environmental sustainability is the circular economy that is not the main concern in Thai furniture, many Thai furniture companies provide environmentally friendly products as their marketing strategy. PSS is also used by many companies as a strategy to increase their sales. In the Thai furniture industry, circular economy and environmental sustainability are not the objectives of offering PSS but most people in the Thai furniture field are aware that material leakage minimization is usually a consequence of it.

4.2 Phase 2: A cross-case analysis

The cross-case analysis compares the similarities and differences of the individual cases. The cross-case analysis is first conducted between the same PSS-related information source (PSS providers, PSS consumers, and other PSS-related professionals) to explore specific investigation results of each PSS-related information source. Then the inclusive cross-case analysis of all PSS-related information sources is conducted as a summary

4.2.1 PSS providers cross-case study (3 PSS providers cases)

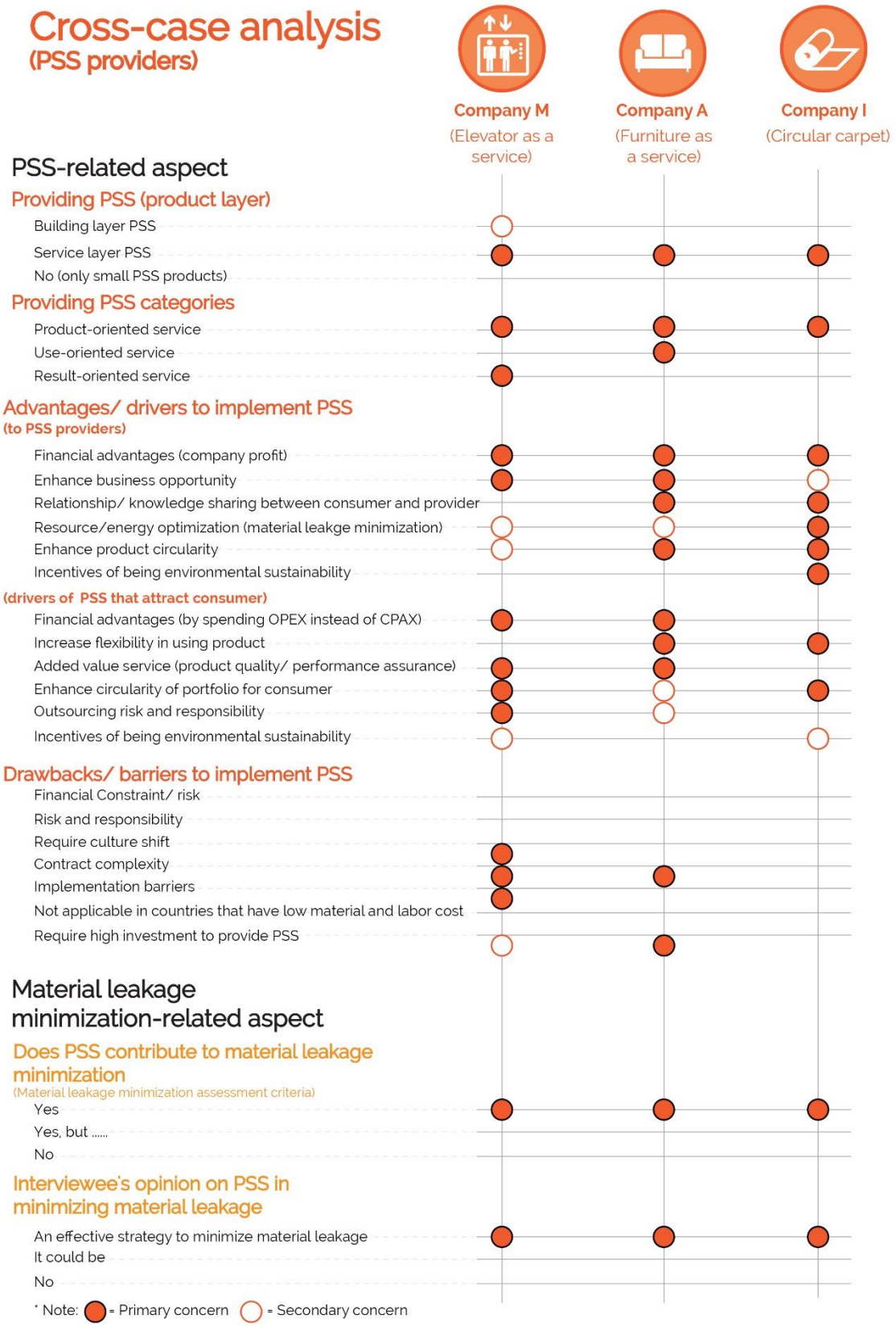

Figure 28: PSS providers' cross-case analysis result (own illustration)

PSS-related aspects

Providing PSS (product layer)

From the studying of three PSS providers' cases, two of them (company A and I) provided the service layer PSS product, while another PSS provider (company M) provided partial service and building layer.

Company M: elevator as a service (service layer: elevator car and system, building layer: elevator shaft)

Company A: office furniture as a service (all of them is considered service layer component)

Company I: circular carpet (service layer component)

Providing PSS categories

All three PSS providers provided product-oriented services. Two interviewees from the PSS providers mentioned that product-oriented service such as maintenance, repair, and upgrade of the product is usually provided as complementary when offering PSS products to the consumer. The product-oriented service not only helps PSS providers optimize their resource consumption (long-lasting product) but also best facilitate consumer in using a product without any burden or problem.

A use-oriented service is only provided by company A (furniture as a service). The furniture subscription and furniture pool strategies could improve the efficiency of the provided PSS product.

A result-oriented service is only provided by company M (elevator as a service) in a form of a performance contract (pay-per-one vertical movement). Since one of company M's slogans is providing a "quality driven" product, offering a pay-per-one vertical movement is a necessary strategy to ensure the provided product functionality/ quality to consumers.

Advantages/ drivers of PSS that can attract consumer

According to three PSS providers' cases study, three of them mentioned that the driver to providing PSS is to enhance the business opportunity to the market for earning more profit. Providing PSS could contribute to the circular economy which means reducing natural resource extraction while stimulating economic growth. Environmental sustainability is also a driver for PSS providers to offer PSS as it could attract consumers to use PSS, said three of the PSS providers' interviewees. Offering PSS brings about the opportunity to optimize resource utilization which not only helps PSS providers to lessen their production cost but also reduces CO2 emission during the PSS product life cycle.

PSS advantages that are mentioned by 2 PSS consumers (the company M and A) are

1. Financial advantages to both consumers and providers while offering PSS. While offering PSS, PSS providers could benefit from earning a constant income (monthly/ yearly). From the consumer side (from what PSS providers have experienced), they can benefit from accessing the product functionality by spending as OPEX instead of CPAX. This allows consumers to allocate their OPEX to facilitate their main business.

2. The added value in the use of the product by using PSS could be a driver for consumers to use PSS. A guaranteed performance contract or maintenance and upgrade contract from a PSS provider could ensure that the consumers will use the best product without any problem or burden.

Other PSS advantages that are also mentioned by 2 PSS consumers (company A and I) are

1. Increasing the use of product functionality; The consumers could benefit from the flexibility of using a product with less commitment, the products could be changed or returned to the PSS provided once they no longer want it.

2. Implementing PSS could enhance the relationship between consumers and providers. PSS is to provide a combination of services and products to meet the consumers' demands. The consumers could benefit from using products that best meet their demand, while PSS providers might have the opportunity to provide future PSS products to the same consumers once the relationship between the two parties is going well.

Furthermore, Company M mentioned outsourcing risk and responsibility in using PSS products is also the main driver for their consumer to use company M products (elevator as a service). An elevator is a complex product that requires technical knowledge and specific equipment for maintenance. For consumers, it is better to allocate product responsibility to the PSS provider in order to avoid those complications.

Drawbacks/ barriers of PSS that might be issues for consumer

Since companies M and A are providing a higher level of servitization PSS, the two companies have encountered that the complexity of the contract is always a barrier for consumers. PSS is a relatively new procurement in CRE and construction industry, therefore it requires a culture shift to use or to provide PSS.

To initiate providing PSS as a PSS provider, initial capital is required. The representative from company A said that they invest around 12 million euros to initiate offering PSS. This might be a huge barrier for SMEs who interesting in providing PSS.

Company M is the only one out of three PSS providers who encounter the implementation barrier. An elevator is probably considered a service layer component according to Pushkar (2015), but there is some part of it such as the elevator shaft which needs to be attached to the building. This might be considered a partial building layer component. Therefore, the building layer implementation barriers become the main challenge for company M in providing PSS. This complexity could be a barrier for consumers and PSS providers in implementing Elevator as a service. To overcome this, both consumers and PSS providers need extra collaboration and a strong ambition.

Material leakage minimization-related aspect

Does PSS contribute to material leakage minimization

From the result of three PSS providers' case studies regarding material leakage minimization, it showed that the value material leakage minimization contributors of PSS are better compared to an average linear economy product (same product types). Also, the PSS product portfolio circularity of all three cases is improving since providing PSS.

Interviewee's opinion on PSS in minimizing material leakage

From the PSS providers' perspective, all 3 interviewees from 3 PSS providers believe that PSS has the potential in minimizing material leakage within office refurbishment. This could also be the main driver to attract consumers to use PSS more in the future.

PSS providers cross-case study finding summary

According to the 3 PSS providers' cases, company A and company I provide an absolute service layer PSS. Meanwhile, company M provides a partial service layer PSS as some parts of its PSS product need to be attached to the building (e.g. an elevator shaft). By doing so, company M encounters more difficulty in implementing PSS due to the building layer PSS implementation barriers (building law and management in construction). However, Company M can deliver its PSS successfully by having extra collaboration between project (construction) stakeholders and extra procedures to avoid the building layer PSS implementation barriers.

All three cases study facilitate their consumers by providing a product-oriented service, while company M and company A also provide result-oriented service and use-oriented service respectively in addition to the provided product-oriented service.

From the case study, the first objective of most PSS providers is to gain a market share which could result in earning a higher profit for the company (PSS providers). The following objectives are environmental impact reduction and optimizing resource utilization. Material leakage minimization is not yet considered the first objective by providing.

Since PSS is a newly emerged procurement strategy for corporate real estate, a cultural shift in using PSS and the complexity of the PSS contract is the obstacle for inducing a consumer to use PSS.

In all cases, the material leakage contributions of PSS are improved when implementing PSS which leads to a greater circularity in PSS's provider portfolio. The material leakage within the PSS product life cycle is reduced.

However, the result of the case study shows that the level of material leakage minimization does not rely on the provided PSS categories and level of servitization but on material flow and the PSS material leakage minimization contributors. This is aligned with the findings of Corvellec and Stal's (2017) findings. From the case study, the circularity of company I, which only provides product-oriented service that has the least level of servitization among the three PSS categories of Tukker (2004), is greater than company A's nowadays.

4.2.2 PSS consumer cross-case study (3 PSS consumers' cases/ CREM)

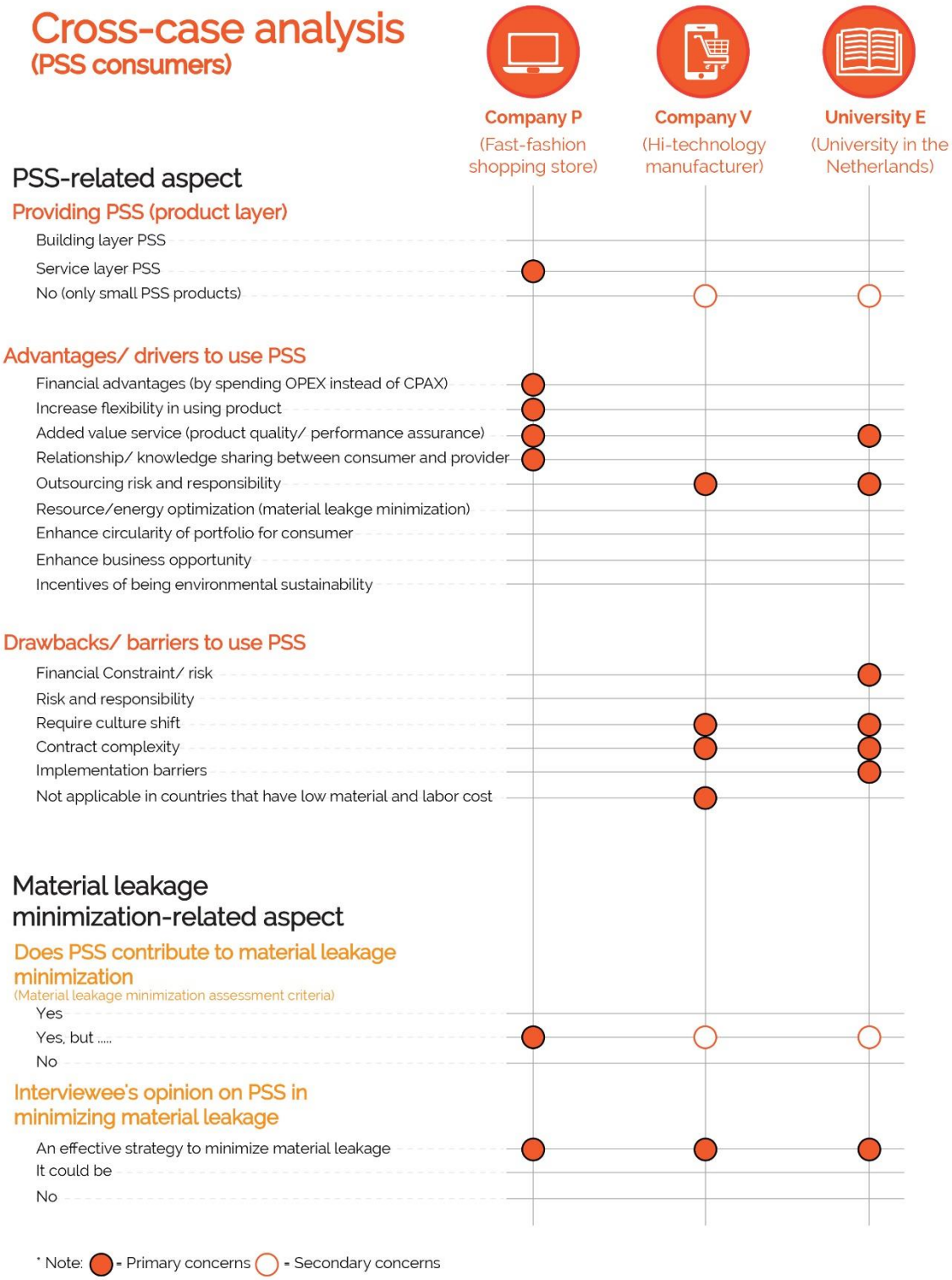

Figure 29: PSS consumers cross-case analysis result (own illustration)

PSS-related aspects

Providing PSS (product layer)

According to the 3 PSS consumers case study, no one uses building layer PSS. Company P uses three service layer PSS, while university E use several service layer PSS. Company V only use small ordinary PSS products such as copy machines and coffee machine which has been typical leasing products for a long time, but they are not really concerned with CREM.

Advantages/ drivers of using PSS

From 3 PSS consumers (CREM) the PSS advantages that are most mentioned (by 2 out of 3 interviewees) are an added value service and outsourcing risk and responsibility of the product while using PSS since this helps consumers to access the best product functionality without any burden in using products by paying a relatively small amount of expense.

Financial advantages of using PSS, an increase in flexibility of product use, and relationship development between consumers and providers are mentioned as PSS advantages by company P. Since company P is a newly established company with limited capital and high alteration in CRE, the company P store manager thought that those mentioned advantages of using PSS could best support the company P CRE (physical shopping store).

Unfortunately, environmental sustainability and material leakage minimization are not yet mentioned as the main driver to use PSS by any consumers (3 cases).

Drawbacks/ barriers of using PSS

A University E who has never used a building service layer or any large-scale PSS mentioned that they want to use the PSS in those PSS components as well, but using those PSS components requires a huge change in the organization. University E is not ready for the change (culture shift). Using PSS does not match the current financial structure of university E, also the contract is too complex. Lastly, the implementation barrier of the building layer is a huge barrier to using the building layer PSS for university E nowadays.

A representative of company V said that its organizational paradigm, which only possesses the CRE and major facilities by traditional purchasing, is a great barrier to the use of PSS in CRE.

Company P, the only company which does not locate in Europe mentioned PSS might not yet be suitable for underdeveloped or developing countries where the environmental sustainability concern, labor cost, and material cost are low. In those countries, using the linear economy (take-make-dispose) is way too cheap and less complicated.

Material leakage minimization-related aspect

Does PSS contribute to material leakage minimization

Due to most of the using PSS from three consumer cases being fully responsible by PSS providers, all the burdens which include product disposal at the end of the contract or the end of the product life cycle are done by PSS providers. Therefore, all the material leakage from using the PSS product of three consumer cases is near zero. However, the improvement of material leakage minimization in consumers' real estate portfolios after using PSS is ambiguous since the PSS product that they use already generates a small amount of material leakage.

Interviewee's opinion on PSS in minimizing material leakage

From the PSS consumers' perspective, all 3 interviewees from 3 PSS consumers are aware of and believe that PSS has the potential in minimizing material leakage within CRE.

PSS consumers cross-case study finding summary

According to the analysis of three PSS consumer cases study, the most used PSS is the service layer or other small leasing product. No one has had experience in using building layer PSS.

Different consumers are attracted by different PSS benefits namely, outsourcing risk and responsibility, financial advantages of using PSS, and access to high-quality products without capital. However, applying PSS to the CRE requires a culture shift since PSS works differently from traditional purchasing procurement. Therefore, the complexity of the contract and management is always present as a PSS use obstacle for the consumer.

Even though most of the interviewees (PSS consumers) are aware that material leakage minimization is a consequence of using PSS, it seems to be not yet the main driver in using PSS for consumers.

4.2.3 Other PSS-related professionals (2 professionals/ cases)

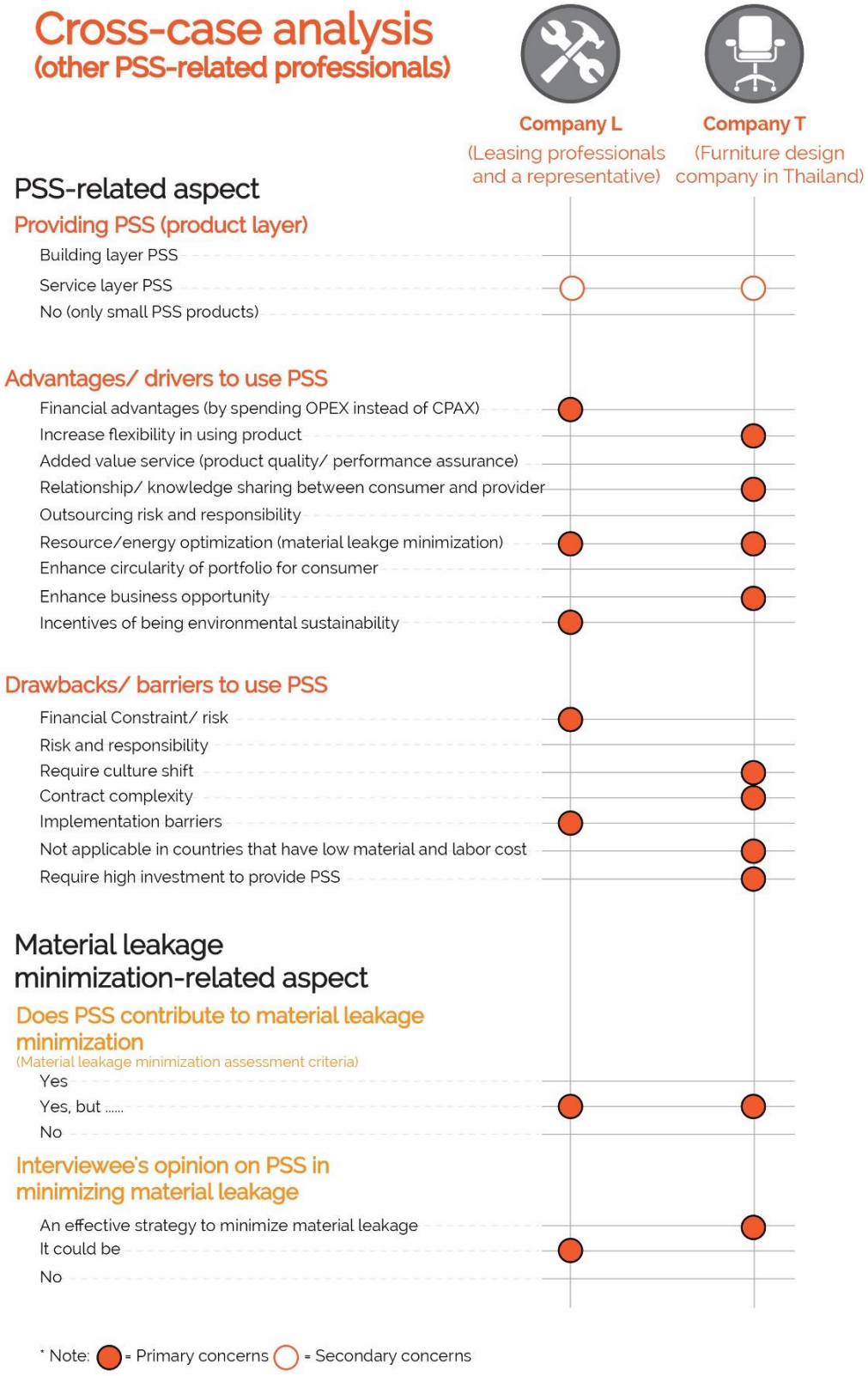

Figure 30: other PSS-related professionals' cross-case analysis result (own illustration)

PSS-related aspects

Experiencing or relating to PSS (product layer)

Even though both PSS-related professionals are neither PSS providers nor PSS consumers, they both indirectly influence service layer PSS implementation. Both of them can provide an overview of the PSS (service layer product) from their field of knowledge and experience.

Advantages/ drivers of PSS that can attract consumer

Both of the other PSS-related professionals see that resource optimization is the advantage of using PSS. However, in some contexts such as in developing countries where environmental sustainability is less concern and material and labor costs are cheap, the resource optimization characteristic of PSS is often disregarded.

Company L, leasing professionals and representatives in the Netherlands, mentioned the financial advantages is a benefit of using PSS. PSS consumers could access the PSS product functionality without capital. Furthermore, an incentive for being environmental sustainability is a considered major benefit of using PSS. Nowadays in many European countries, governments and many institutions are promoting environmental sustainability products and activities by giving incentives, tax reductions, and offering special interest (loan, mortgage) for environmental sustainability projects.

Company T, a furniture design company in Thailand is considering providing PSS furniture soon. The owner of company T said that the major PSS benefits to the PSS providers are an enhancement of business opportunities to the market for earning more profit. The PSS provider and consumer relationship, which is often developed during PSS implementation, could commonly benefit both the PSS provider and consumer.

Company T mentioned that a key benefit of PSS to PSS consumers is a high level of flexibility in using PSS products. Such as chairs and tables are often leased for 1-2 days for organizing an event (in Thailand).

Drawbacks/ barriers of PSS that might be issues for consumer

Different Professionals (company L and V) has a different view on the drawbacks and barriers of implementing PSS since they. The difference in the view might derive from the different contexts and situations of each professional.

Company L, a European (Dutch) company, sees the financial risk in providing PSS as a drawback for the PSS providers. For implementing PSS, the PSS providers require time, a huge amount of capital investment, and research and development to minimize uncertainties and risks. Due to the huge resource required for implementing PSS, the PSS providers need to set an offered service fee wisely in order to cover all the investments they made at the beginning and earn sufficient profit. Providing PSS is sometimes financially risky.

Moreover, in the European context such as in the Netherlands, the institutional barriers could act as a hindrance for implementing PSS. For example, huge and building-attached PSS components are difficult and sometimes not worthy to be provided as PSS.

In the context of developing countries where environmental sustainability is less concerned, material and labor costs are low, PSS is not yet prevalent in many industries, unlike the European countries. The owner of company T, a furniture design company in a developing country (Thailand), mentioned that the major barriers to implementing PSS in the developing country are a culture shift in providing and possessing products as a service. Most people there think that it is a complicated procurement strategy that is not worth implementation (practically and financially).

Material leakage minimization-related aspect

Does PSS contribute to material leakage minimization

Both of them are aware that PSS could contribute to material leakage. However, as they are aware, the level of consideration of PSS material leakage minimization feature is low in the European country and extremely low in developing countries (Thailand).

Interviewee's opinion on PSS in minimizing material leakage

An interviewee from company L believes that the PSS could be a strategy to minimize material leakage, but it is often disregarded since he mostly associates with movable or stand-alone leasing products such as trucks, or equipment which normally generate less amount of material leakage. Therefore the minimizing material leakage feature of PSS is not yet considered a significant benefit.

Company T's owner thinks that PSS can be a material leakage minimization contributor, in case the implementation of PSS is successful.

PSS providers cross-case study finding summary

According to the analysis of two PSS-related professionals who have different knowledge and experience regarding PSS from different parts of the world, the benefits and drawbacks of implementing PSS from their perspectives are different. Context and environment where the PSS is taking place are highly influential in PSS implementation.

In any case, they are both aware that material leakage minimization is mostly a consequence of PSS implementation, but from their experience material leakage minimization feature of PSS is often disregarded by PSS consumers.

4.2.4 Inclusive Cross-case study of all PSS-related information sources result

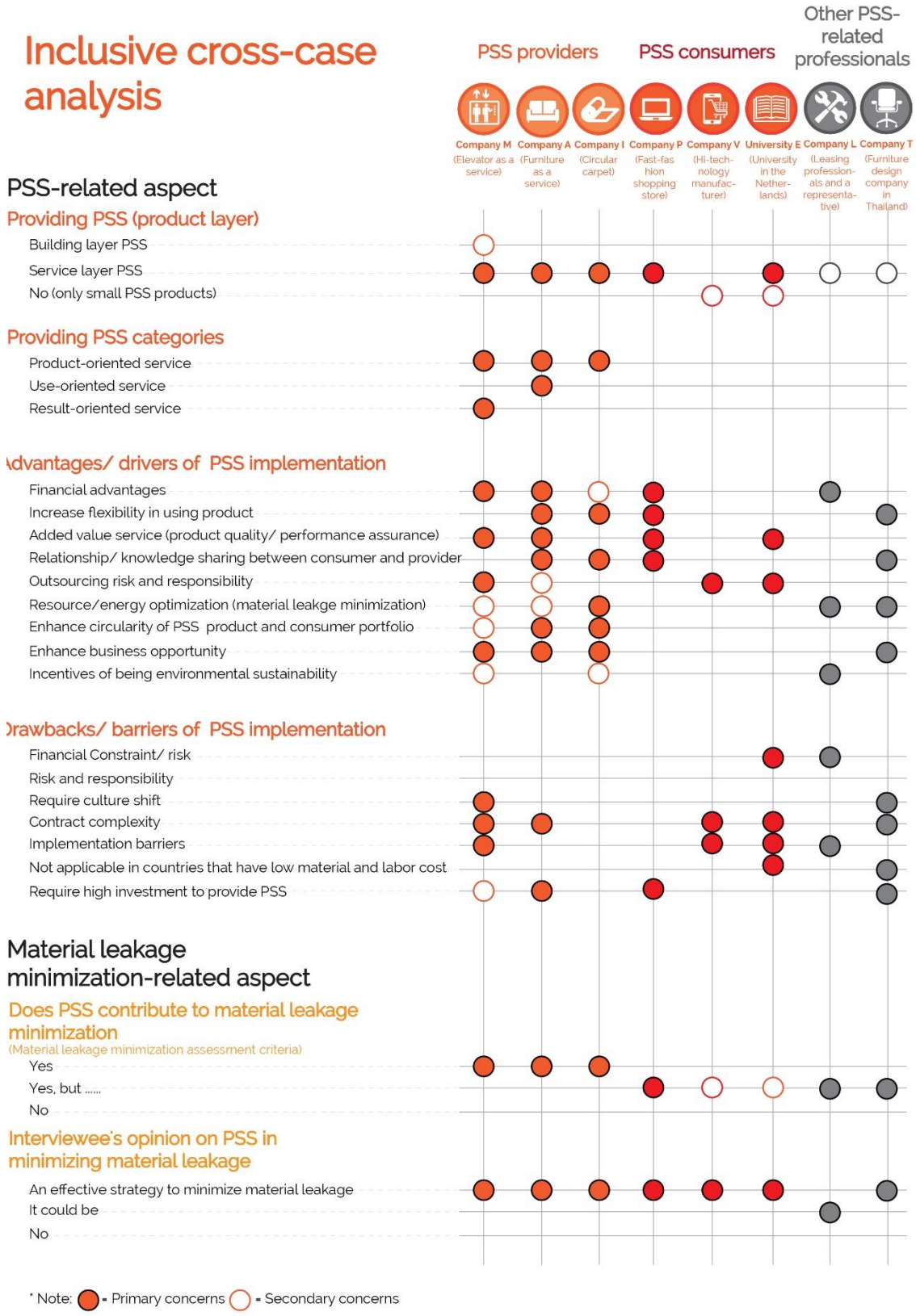

Table 31: a cross-case analysis result (own illustration)

Using/ providing PSS

Of 8 interviewees, only one has ever experienced providing or using (partial) building layer PSS, it is company M that is providing elevator as a service.

Providing building layer PSS has high risk and many challenges, one important challenge is implementation barriers. Also, financial capital and sufficient company facilities are required to develop the PSS. Therefore, the building layer PSS is very rare in the market. Fortunately, since company M is a mega company it has both financial capital and sufficient company facilities to develop an elevator as a service. Building layer PSS Implementation barriers are one of company M's hindrances in providing elevator as a service but company M could find a solution to overcome them (see 4.1.1, case 1).

5 out of 8 companies have experience in providing and using service layer PSSs. Company A and Company B are both PSS providers who are providing service layer PSS. They are both mega-companies in Europe for a long time before starting to provide PSS. Since the service layer PSS is not affected by implementation barriers, it is easier to provide PSS products to the market.

Using/ providing which PSS categories

In this section, only the PSS providers are mentioned as the using/ providing PSS categories refer to the provided strategies of each PSS. Therefore, only PSS providers can deliver insight information about the provided PSS categories.

In the case study, three cases of PSS providers are investigated. All of them offer product-oriented services to their PSS consumers as it is a fundamental service that is provided to facilitate consumers in accessing and using the PSS. In addition, the offered product-oriented service could lead to material leakage minimization. The offered service such as maintenance upgrades results in longer life of the product. A take-back agreement after the product reaches its end of life could lead to a closing material loop.

A use-oriented service is only provided by company A, furniture as a service. A furniture subscription and furniture pools allow the provided furniture being more intensively used and properly treated by company A after the end of the consumers' contract. Since the products are used and treated more efficiently, the need for production is reduced.

A result-oriented service is only offered by company M, elevator as a service. Performance contract, pay per one vertical move is offered to company M's consumer to guarantee the offered PSS quality and performance that company M and consumers agree together. This allows company M to optimize rhesource utilization by using substituted or circular elevator elements. Since more circular elements are reutilized and provided to the consumer, fewer residual and broken elevator elements are disposed of (landfilled) or incinerated which leads to less material leakage.

Advantages/ drivers of using PSS

There are almost 10 major advantages of using PSS that were pointed out by the interviewees. Resource and energy optimization is the advantage of using PSS which was mentioned by most interviewees (5 out of 8). It was mentioned by all the PSS providers (3 companies) and other PSS-related professionals whose businesses are positioned on the PSS provider side. The PSS provider, who knows the whole life cycle of PSS products, is aware of the resource and energy optimization which are consequences of providing PSS, while the consumer who does not aware of it might not see this as the primary driver to use PSS.

Half of the interviewees (most of them are PSS providers) believe that providing PSS could enhance their business opportunities which could generate high profit for the company, even though it requires a great amount of capital.

A special relationship between consumers and PSS providers is also one of the interesting advantages of using/ providing PSS as two PSS providers, one corporate (consumer), and one other PSS-related professional mentioned it.

Financial advantages, the added value of service, and flexibility in using PSS are considered as one the important drivers of using PSS are stated by half of the interviewees. These benefits of using PSS could attract consumers to use PSS over traditional purchasing procurement.

2 consumers see the product responsibility that is allocated to the PSS provider as an advantage of using PSS. By doing so, they only use those PSS products conveniently without any concern.

An advantage of PSS in contributing to environmental sustainability is only pointed out by 2 PSS providers. Since environmental impact become a global concern, the government or institution of many countries is promoting a circular economy and environmental sustainability by offering an incentive for being circular or environmentally friendly. Even though it is not a key driver for consumers or providers to use and provide PSS, it is a beneficial side effect that comes up with PSS.

Drawbacks/ barriers of using PSS

Since the PSS is a relatively new emerged procurement strategy and it is completely different from traditional purchasing, culture shift and contract complexity are often PSS challenges. Most of the interviewees (5 out of 8) see the contract complexity as a barrier to making people start using PSS. A cultural shift, which is mentioned by half of the interviewees, is required for both the provider and consumer sides to change one (company or corporate) mindset in providing or using PSS. Nowadays, in the market, many companies resist a change in the company mindset and culture in order to use PSS, especially the company that has been operating for many decades. Therefore, PSS has not yet been such a prevalent procurement strategy in the market.

Implementation barriers are the major hindrance of PSS, especially building layer PSS. It is undeniable that the barriers are key obstacles (see 4.1.1) which makes building layer PSS very limited in the market. The implementation barriers of PSS are mentioned by 3 out of 8 interviewees.

Financial constraints/risks and the limited amount of capital of the provider who would like to provide PSS are barriers to initiating PSS. One of the interviewees said the main problem of a

PSS provider is having sufficient capital to produce and offer PSS. It is very difficult for a small company to start providing it.

2 of the interviewee who comes from developing countries stated that PSS might not applicable for the country that has low material and labor cost, and does not encounter material scarcity. People incline to traditional purchasing instead of PSS since it is less complex and might be cheaper in a long run there.

Does PSS contribute to material leakage minimization (Material leakage minimization assessment criteria)

The answers of the interviewees to this question depend on what PSS-related role they are. All of the PSS providers reveal that the provided PSS could contribute to the material leakage minimization since most of the material leakage minimization contributors (Product life cycle, efficiency of resource utilization, Waste recovery rate, and product circularity) are greater by using PSS compared to the traditional model.

5 interviewees, consumers, and other PSS-related professionals are aware that PSS could reduce material leakage, but from what they experienced, only a minor amount of material leakage in their real estate portfolio is reduced by using PSS.

Interviewee's opinion on PSS in minimizing material leakage

Almost all of the interviewees agree that PSS can be an effective strategy to minimize material leakage according to their personal opinions. Only one of the interviewee who is other PSS-related professionals think that PSS could minimize material leakage in case the PSS is further developed.

Summary of the cross-case analysis

From the case study and interviews, the different parties, companies, and professions have perceived and experienced PSS from different angles. On one hand, PSS providers are striving for the best profit for the company by providing PSS. On the other hand, PSS consumers (corporate) use PSS to best facilitate their business. In any case, material leakage minimization is a consequence of PSS implementation that most of the interviewees are aware of it.

The primary objective of PSS providers for delivering PSS is to enhance the business opportunity for earning more profit. For the sake of the PSS providers, optimizing resource and energy consumption is the main strategy of PSS to earn more profit by reducing resource capital. The provided strategies such as product take-back program, material passport, product monitoring, product subscription, and many more not only mean to best meet the consumer demands but also directly lead to material leakage minimization.

The main aim of PSS consumers (corporate) who use PSS is to optimize their real estate management. The advantages such as outsourcing risk and responsibility, the added value service, financial advantages, and flexibility in using the product are essential drivers to use PSS over material leakage minimization, although most of the PSS consumers are aware that PSS could reduce material leakage.

Other PSS-related professionals see that PSS is becoming a popular and interesting procurement strategy for many industries. However, further development of PSS is still required as not all products/services and contexts have been yet suitable for PSS implementation.

CHAPTER 5:

DISCUSSION AND CONCLUSION

5. Discussion and conclusion

5.1 Answer to the research questions

This research aims to investigate how PSS could minimize material leakage within CRE (especially office refurbishment). The answers to the research questions are combinations of theoretical research findings and empirical research findings.

The answer to the sub-research questions and the main research question is indicated in sub-chapters 5.1 and 5.2. Further reflection and discussion are presented in the sub-chapter 5.3. The contribution of the research, limitations, and further research recommendations are in sub-chapter 5.4, 5.5, and 5.6 respectively.

RQ.1: What is the Product-service system (PSS)? And what is the potential of PSS to minimize material leakage in office refurbishment?

Answer RQ1:

The product-service system (PSS) is a procurement strategy that provides an integration of tangible products and intangible services to meet the consumer's demand. Most of the PSS product ownership remains with the PSS providers, and consumers can access or possess the product in different ways such as leasing or subscribing instead of traditional purchasing. By doing so, the PSS products are treated more efficiently and properly by the PSS providers.

According to Tukker (2004), PSS could be classified into many categories according to a level of servitization and procurement strategy, namely product-oriented service, use-oriented service, and result-oriented service. A product-oriented service stands for a low level of servitization, while a use-oriented service and result-oriented service stand for an intermediate and high level of servitization accordingly. Each PSS category provides products/services differently to best serve different consumers' needs.

The higher level of PSS servitization offered to consumers, the lower level of product responsibility taken by consumers. Since the consumers are less responsible for the product while using/ possessing it, material leakage caused by using the product is reduced in accordance with the level of the product's responsibility.

Many researchers claimed that PSS could directly contribute to the circular economy which simultaneously contributes to environmental sustainability and economic growth. Material leakage minimization is one of the circular economy and PSS implementation objectives.

According to the literature review, several PSS characteristics could induce material leakage minimization contributors, namely

1. Proper product treatment by PSS providers

2. Delivering the product functionality using the most cost and resource-effective way by PSS providers

3. Support by specialized facilities and knowledge of PSS providers in PSS implementation

These PSS characteristics could bring about material leakage minimization contributors as follow.

1. Product life cycle extension

2. The efficiency of resource utilization enhancement

3. Higher waste recovery rate (End-of-life product management)

4. Product circularity improvement (design for being recyclable, allowing product flexibility in substitution)

Once these material leakage minimization contributors are present, resources (including products and materials) utilization will be optimized. As a result, there is less material leakage within the PSS product life cycle

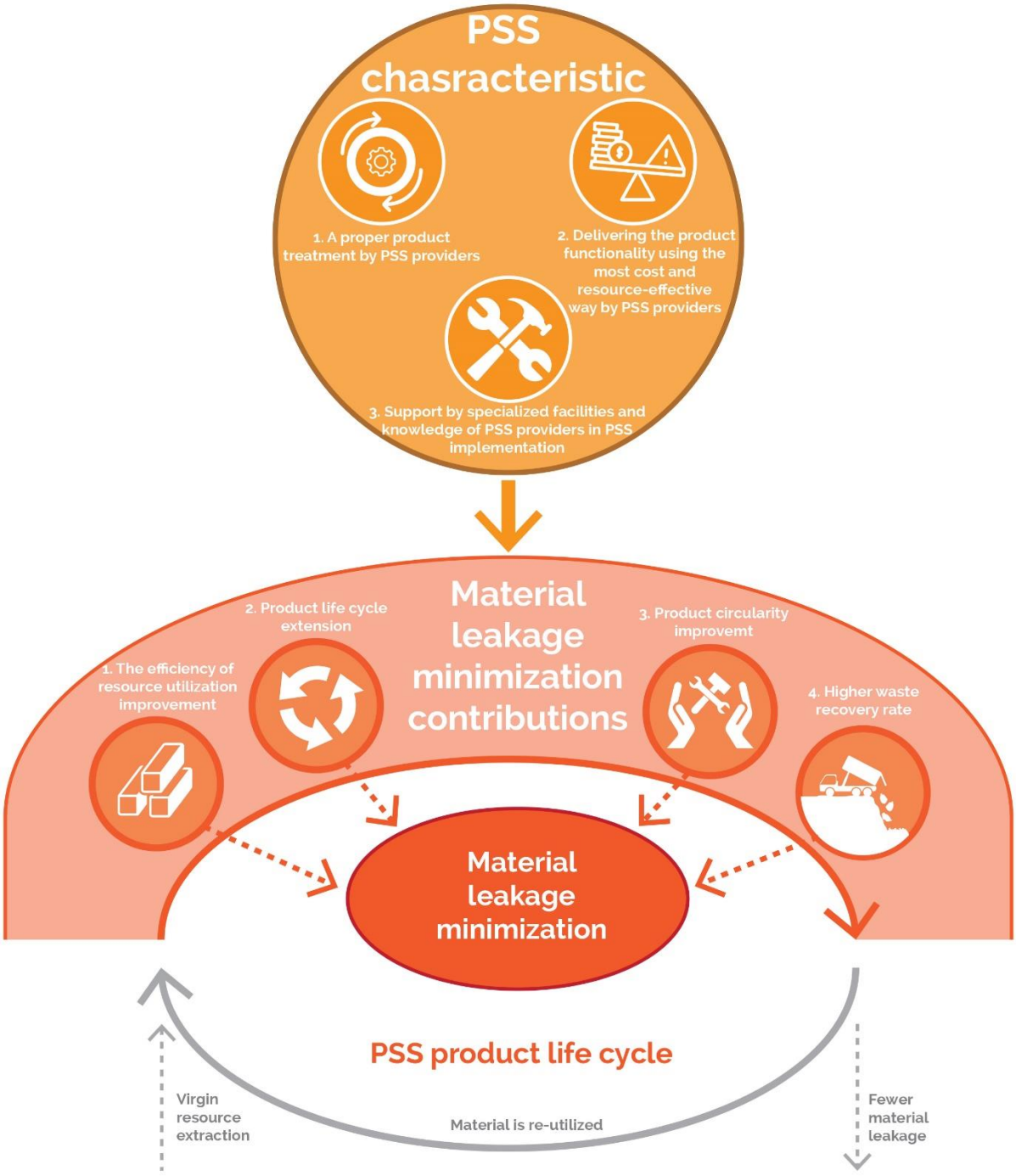

Figure 32: The PSS characteristics which induce material leakage minimization contributors (own illustration)

The result of the empirical research is in line with the theoretical research. According to three PSS providers' case studies, the PSS characteristics which could bring about material leakage minimization contributions are present in all cases. The material leakage minimization contributions are induced by those PSS characteristics which result in a reduction of material leakage within the provided PSS products' life cycle. Thereby, the circularity of the PSS products is greater.

RQ2: In real practice, to what extent is material leakage minimized by the product-service system?

Answer RQ2:

To affirm the theoretical research finding which indicates that PSS has the potential in contributing to material leakage minimization, the study of PSS in real-life practice regarding material leakage has to be conducted in empirical research (case study). The successful PSS providers that have experience in delivering PSS products to CRE are studied. The study of three PSS providers, namely Company M (elevator as a service provider), company A (Furniture as a service provider), and company I (circular carpet provider), on material leakage minimization are conducted as case studies.

The investigation of 3 PSS providers' cases shows that the PSS characteristics, that could bring about material leakage minimization contributors, are present within the provided PSS strategies in all three cases even though they are providing PSS with different PSS types. Those PSS characteristics induce material leakage minimization contributors in the PSS product. By doing so, the material leakage within the PSS product life cycle is decreased. As a result, the circularity of the PSS product is improved, it is considered greater compared to similar products that are provided by a linear economy model (see figure 33)

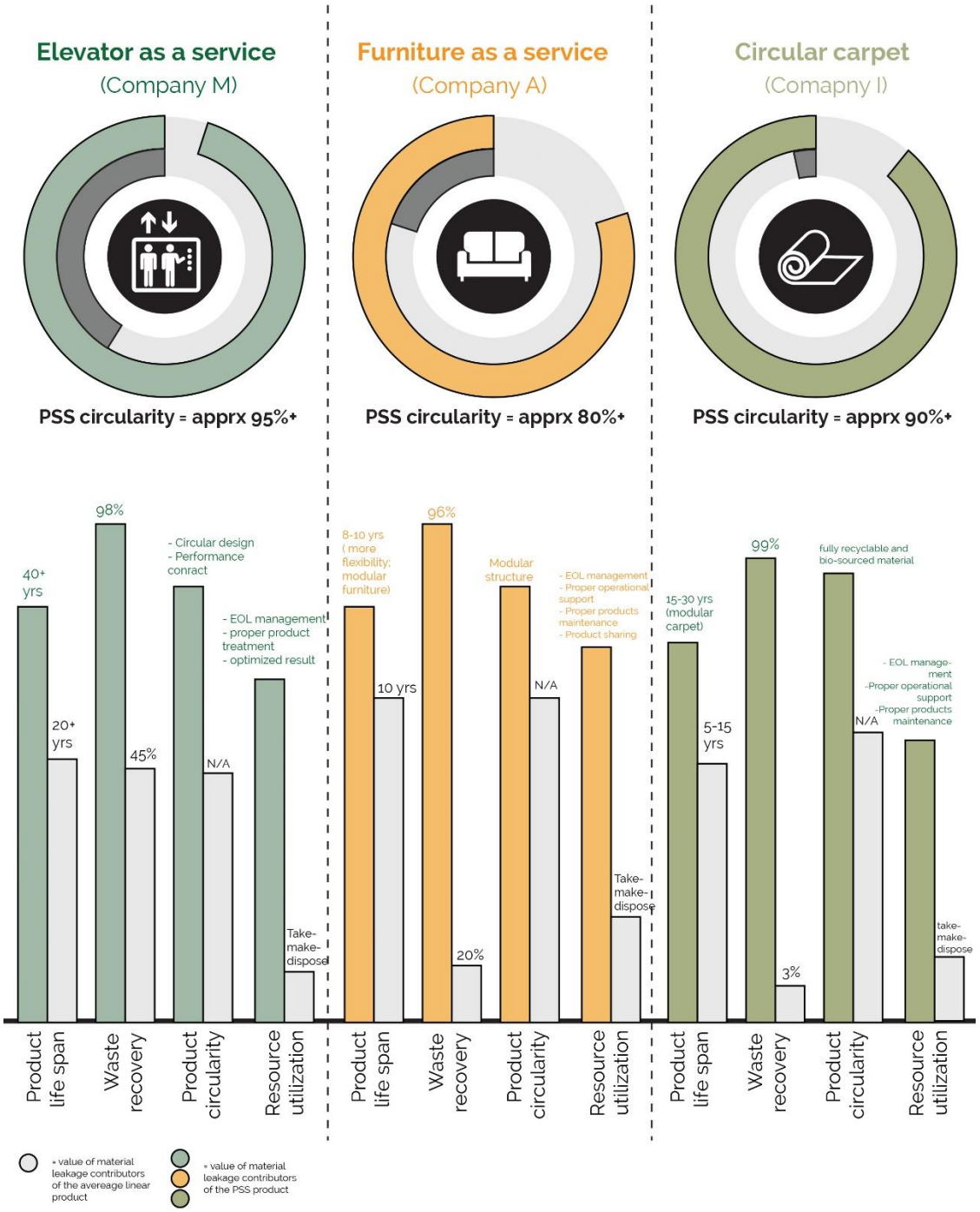

Figure 33: Material leakage minimization contributors and circularity improvement of each case study (own illustration)

Although the amount of material leakage reduction in each PSS case is not yet completely accurate in terms of numeric and quantitative data in this research, the result of all three PSS providers' case studies leads to the same conclusion that the material leakage minimization contributions are significantly improved after implementing PSS and reduce the amount of material leakage.

The findings of theoretical and empirical research are aligned, which demonstrates that implementing PSS could contribute to material leakage minimization.

RQ3: What are the benefits of a Product-service system (PSS) to the PSS providers and consumers?

Answer RQ3:

Potential benefits of PSS (Theoretical research)

According to the literature review, many researchers mentioned that PSS is a procurement strategy that could directly contribute to a circular economy. PSS not only brings about economic and environmental benefits but also provides various additional benefits to PSS providers and consumers (CRE).

Environmental sustainability is a major benefit to PSS implementation that is mentioned the most besides economic benefits in PSS-related literature. Since most of the PSS product ownerships remain at the PSS providers, products are treated more properly and efficiently throughout their life cycle (including after the end of their life). This allows the PSS providers to optimize resource utilization and resource extraction and material leakage are reduced within the PSS product life cycle, which could contribute to a circular economy.

The improvement of PSS product circularity benefits PSS providers, consumers, and the environment. There is the less environmental impact from PSS implementation as the product becomes more circular. The resource extraction for manufacturing a product and material leakage during and after the product life cycle is limited since the resource utilization is optimized by PSS providers. Optimizing resource utilization benefits PSS providers in improving their product portfolio circularity as well as their monetary returns. The greater resource optimization in providing PSS, the more benefits the PSS providers received (as the required capital for a resource is reduced), as well as an improvement in consumer satisfaction since the providers still delivered the agreed product functionality to consumers.

Furthermore, consumers could get an incentive for being environmentally sustainable by using a circular economy procurement strategy (and product). This might improve a consumer asset value since a greater level of building environmental rating could increase the consumer's real estate value. For instant, tenants and investors may be willing to pay more for a LEEDS-certificated rating building.

Another major benefit to consumers when using PSS is the financial advantage. PSS could help satisfy consumers' demands, for example, by having a high-quality lighting system, with less or without using their own capital. By spending OPEX instead of CAPEX in using or possessing products, the consumer can utilize the remaining capital on their main business or other investment opportunities. Besides, using PSS could also allow consumers to access a high-quality product with cost-effective fees since the provided PSS is often supported by the product-related facilities and knowledge of the PSS providers, therefore the consumer can benefit from proper support and an economy of scale from the PSS provider manufacture size.

Since most of PSS product ownership remains to the PSS providers, PSS product responsibility and risk are mostly allocated to the PSS providers. This results in lessening consumers' burden on the product during and after the end of the product life cycle. For instant, the maintenance, repair, and disposal or recycling of the product are usually done by PSS providers. This is considered a great benefit to consumers who use certain types of products that require specialized repair and maintenance services such as servers or hi-tech devices.

PSS could enable more flexibility and adaptability in product use. The consumers can change or return the products to the PSS providers once the products are no longer wanted after a certain period of the PSS contract. Furthermore, the guarantee of upgrades and performance of the product could ensure that the consumers can fully utilize the product throughout the contract period.

Several researchers define PSS as a co-creation procurement strategy between PSS providers and consumers which means the provided product functionality is usually best aligned with the consumers' demand. This improves consumers' satisfaction and consumers-providers relationship development. Furthermore, PSS providers could gain more market share as the offered PSS benefits could attract a number of consumers.

Real practice PSS implementation benefits (Empirical research)

8 cases were conducted to understand what is considered the main benefits or drivers in providing and using PSS from real PSS providers' and consumers' perspectives.

According to the PSS providers' case studies (3 cases), the primary objective in providing PSS is to enhance their business opportunities to gain more company profit. Resource optimization (material leakage minimization) and product circularity improvement are considered the second prioritized benefit by PSS providers. Optimizing resources could help PSS providers to get higher incentives in providing PSS and reduce environmental pressure.

The relationship development between consumer and PSS providers are considered a third prioritized benefit of PSS providers. With a better relationship between PSS providers and consumers, consumers are more likely to continue using PSS products from the PSS providers which could also contribute to PSS providers' income.

From the case study, the benefit of PSS that is mentioned the most as the first priority from the consumers' perspective is "financial advantage in using PSS" and "outsourcing risk and uncertainty". Meanwhile, "access to the high quality or guaranteed performance product" and "increased flexibility in using a product" are considered second and third prioritized benefits respectively by several PSS consumers.

The improvement of portfolio circularity and material leakage minimization by using PSS are not considered the first three PSS benefits from PSS consumers' point of view. However, all of the PSS stakeholders (from 8 cases) are aware that material leakage minimization is a consequence of PSS implementation

Regarding material leakage minimization, from the case study, it is not the primary objective of most PSS-related parties in implementing PSS. Consumers often choose PSS that best facilitates their businesses. Drivers such as financial advantages, outsourcing risk and uncertainty, and flexibility in using PSS are considered more attractive benefits in using PSS compared to material leakage minimization.

Even though material leakage reduction is not the key factor for consumers to use PSS, it is the consequence of implementing PSS (in all studied cases according to the case studies). All interviewees from 8 cases are aware that using PSS could reduce material leakage. The findings of the theoretical and empirical research are aligned in that material leakage minimization seems to be a consequence of PSS implementation, but is often disregarded (has not yet been seen as a priority benefit) by PSS consumers.

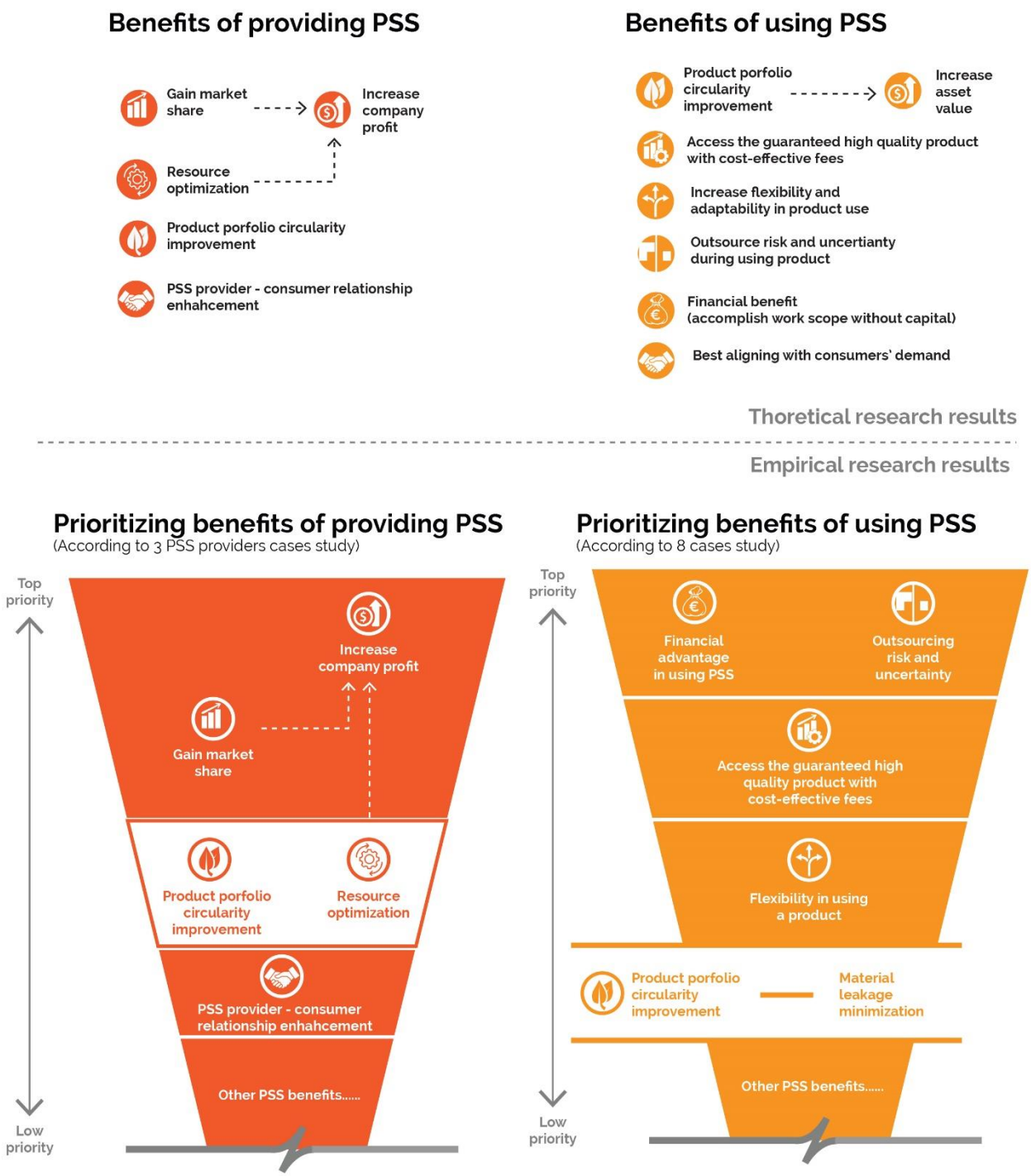

Figure 34: Benefits of PSS implementation to PSS providers and consumers (own illustration)

5.2 Answer to the main research question

Main RQ: To what extent does the Product-Service system (PSS) help corporate real estate (CRE) in minimizing material leakage?

Answer main RQ:

According to the theoretical research and the empirical research (8 cases study), material leakage minimization seems to be a consequence of the PSS implementation.

For a consumer (CRE), there are mainly two advantages in using PSS regarding material leakage minimization. PSS consumers not only use a circular product that generates fewer material leakage amounts but also have less (or no) product responsibility while using PSS products which means material leakage on the consumer's side is reduced accordingly.

From theoretical research, PSS shows the potential to improve material leakage minimization and product circularity. The characteristics of PSS, namely 1. Proper product treatment by PSS providers 2. Delivering the product functionality using the most cost and resource-effective way by PSS providers and 3. Support by specialized facilities and knowledge of PSS providers in PSS implementation, enhance material leakage minimization contributors.

The four material leakage minimization contributors are 1. Product life cycle extension 2. The efficiency of resource utilization enhancement 3. Higher waste recovery rate (End-of-life product management) 4. Product circularity improvement (design for being recyclable, allowing product flexibility in substitution), arises as a result of a preset of the mentioned PSS characteristics. This leads to a reduction of material leakage within the PSS product life cycle and a higher level of PSS product circularity.

The empirical research findings are in accordance with the theoretical research findings which affirm that all the PSS characteristics that can induce material leakage minimization contribution are present in all the studied cases (real practice PSS implementation). Based on the PSS providers' studied cases, by having those PSS characteristics, all PSS material leakage minimization contributors are improved which leads to an improvement of material leakage minimization within the PSS product life cycle. Therefore, the circularity of PSS products is greater compared to similar products that are provided as linear economy products.

Moreover, for consumers, Product responsibility during using PSS is one of the key factors that influence the amount of material leakage minimization on the consumer side (CRE). The product responsibility of the consumer affects the amount of consumer material leakage. When using PSS, more or less product responsibility is allocated to the PSS provider which makes the material leakage of the consumer in using the product reduced in accordance with the level of the product's responsibility.

From conducting this research, the finding of theoretical and empirical research show that material leakage minimization seems to be a consequence of the PSS implementation. However, the PSS material leakage minimization feature has not yet been the primary driver for a consumer in using PSS in the CRE nowadays.

5.3 Further reflection and discussion

According to the 8 case studies, it showed that material leakage minimization is a consequence of PSS implementation. Even though material leakage minimization should be a highly concerning aspect nowadays due to the movement of the real estate and construction industry toward environmental sustainability, it is disregarded by many PSS consumers.

Some assumptions that may cause the material leakage minimization feature of PSS which is often disregarded have arisen during the conduct of this research, which are.

1. Most of the PSS which are provided in the market are small components (service layer components) that already generate a relatively small amount of material leakage.

2. The building layer component that might generate a huge amount of material leakage is almost not provided as PSS in the market due to the implementation barriers. Even though some research shows that it is possible to implement PSS in the building layer, greater collaboration between all PSS implementation stakeholders is required to overcome these barriers.

3. There might be a better procurement strategy for minimizing material leakage other than PSS. Also, the degree of material leakage minimization by PSS has not yet been quantitatively manifested. It is difficult to convince more consumers to use PSS for the purpose of reducing material leakage without clear evidence such as numeric support information.

Material leakage minimization attribute of PSS could be one of the main drivers for consumers to use PSS in the future, but these assumptions must be first manifested and quantified with numeric evidence.

5.4 The contribution of the research

The research contributes to the arenas of material leakage within the CRE, Product-service system, and corporate real estate management (CREM) by establishing the assumption that applying PSS could help CREM to minimize material leakage.

This research is to investigate the relationship between the two concepts that are material leakage and using of PSS within the CRE context. Material leakage issue has often been overlooked during office refurbishment that could cause various negative effects on many involved stakeholders as well as the environment. PSS is a procurement strategy that has the potential for being a proactive solution to the material leakage issue.

The research aims to point out the correlations between material leakage and the use of PSS. Within the research, the identification of what negative effect that cause by material leakage, what PSS potentials contribute to material leakage minimization, how PSS works in providing those potentials in real practice, and what benefit the PSS consumers and PSS providers get from PSS implementation (regarding and regardless of material leakage minimization), are conducted.

5.5 Limitations

PSS is a relatively new strategy for the real estate and construction industry which is developing and not yet stable. The information source regarding using PSS in CRE is limited as well as the amount of successful PSS implementation cases for the CRE. Even though the gathered information for the research is sufficient, the input of the research is not as much as it is expected to be due to a limited content-related resource.

A small number of cases is another limitation of this research. Since applying PSS to CRE is not yet prevalent in the market nowadays. Only a few companies that had experience in PSS implementation are willing to participate in the interviews (as a case study).

Moreover, Since material leakage minimization is not considered the main driver for using PSS, the in-depth information regarding material leakage minimization by using PSS in CRE is limited. The precise number of material leakage reductions after consumers use PSS is not available as a result of limited resources. However, the improvement of material leakage reduction of consumers when using PSS could be implied from the PSS providers' information and the presence of material leakage minimization contributors of PSS.

5.6 Further research recommendations

The PSS is not yet a prevalent procurement strategy in the corporate real estate and construction industry. There is still a gap in both research and real practice areas that should be investigated further, namely 1. The amount of minimized material leakage by using PSS in the building layer and service layer components 2. A strategy development that could overcome the implementation barrier of building layer PSS implementation 3. A deep investigation of material leakage minimization benefits by using PSS in the CRE (economically wise, environmentally wise, and CRE management-wise). Which should come up with numeric support evidence. 4. How to promote the material leakage minimization feature to be the main driver for consumers to use PSS. 5. Input from other material leakage-related professionals such as demolition contractor

Lastly, since the PSS strategy for the corporate real estate and construction industry is continuously developing, a repeat of this study in the future would be valuable as there will be more precise information available and the developed PSS strategy could bring about a better result regarding material leakage minimization and circularity.

CHAPTER 6:

REFLECTION

6. Reflection

The following part of the report aims to reflect on the different thesis-related aspects that contribute to the development of the graduation project (Thesis).

6.1 The relationship between research and design.

As mentioned in the preface this topic could contribute to the answer to my curiosity which is what should be a proactive solution to minimize material leakage in the office refurbishment. This curiosity occurred when I was working as an architect In Thailand. Back then I saw a lot of components and materials discarded to landfill even though they were still functional. I see it is not efficient in both economical and environmental aspects.

Throughout the research conducting, I am always excited in getting new and interesting input regarding the research topic. I think it is one step closer to the answer to curiosity every time I get new input.

However, researching this topic is not easy since the PSS is a relatively new procurement strategy in the corporate real estate and construction industry. It still continues developing and is not yet stable. Therefore, the information from both the literature review and case study (interview) is very limited. Researching a topic that has limited resources is very time consume in finding something.

What I have learned from conducting this graduation project is that the results of the research usually do not go according to the researcher's expectations. In my case, for example, the findings are far different from my expected result.

6.2 Research method

This research is conducted through the literature review and case study. In the beginning, researching a topic that is considered new in the research context, finding proper literature, as well as an interviewee who can provide me with precise information on my expected aspects, is difficult.

For the empirical research, I decided to broaden the investigation scope by conducting several PSS-related stakeholders, namely PSS providers, PSS consumers, and other PSS-related professionals, to get more comprehensive information from different angles and make it more researchable. By doing so the derived information are less precise and varies. Therefore, I shifted my goal in investigation from precise information the broaden information but could explain the overview of the research topic greater.

Eventually, the research outcome changed from what I planned, but can still answer the research questions.

6.3 Research process

During the research, the researcher often overstresses obsessing with conducting research toward the best-expected research result. However, it was learned that taking a break and stepping back to see the overview of the ongoing process is important. This not only helps the researcher to relieve stress but also enhances the researcher's working efficiency since the overview of the work is revealed. Therefore, the researcher could plan and continue work more efficiently. This is in accordance with what I have heard, people should work smart not work hard.

7. References

Ahrend. (2020). Royal Ahrend integrated report 2020

Antikainen et al. (2021). Circular business models: product-service systems on the way to a circular economy. EPA Network

Anttonen, M. (2013). Eco-efficient service as a route towards sustainable development. Laurea Unitersities of Applied Sciences, Department of Management and International Business

Baines et al (2007). State-of-the-art in Product Service-Systems. Innovative Manufacturing Research Centre, Cranfield University, Cranfield, UK

Besch, K. (2004). Product-service systems for office furniture: barriers and

opportunities on the European market. International Institute for Industrial Environmental Economics (IIIEE), Lund University, P.O. Box 196, 22100 Lund, Sweden

Blaikie, N. (2010). Designing Social Research. The Logic of Anticipation. 2nd Edition. Polity Press, Croydon, UK.

BPP. (n.d.). Construction waste. Retrieved from: https://www.betterbuildingspartnership.co.uk/node/679

Bertoli, A. (2017). A Hidden Waste Stream: 9 Million Tons Of Office Furniture Goes To Landfills Annually. CleanTechnica. Retrieved from: https://cleantechnica.com/2017/11/07/a-hidden-waste-issue-8-5-million-tons-of-office-furniture-goes-to-landfills-annually/

Casas-Arredondo, M. et al. (2018). Material and decision flows in non-domestic building fit-outs. The Bartlett School of Environment, Energy and Resources, University College London, London, WC1E 6BT, United Kingdom. Journal of Cleaner Production 204 (2018) 916e925

Casas-Arredondo, M. (2021). Circular economy and office fit-out: an analysis for office fitout processes based on material flows (PhD thesis). University College London, UK.

Clark, T. (2021). London office boom: construction starts increase by 20%. Architectsjournal. Retrieved from: https://www.architectsjournal.co.uk/news/london-office-boom-construction-starts-increase-by-20

Corvellec, H, Stål, H,I. (2017). Evidencing the waste effect of Product-Service Systems (PSSs). Journal of Cleaner Production

Deloitte. (2010). Workplace Flexibility Take control of letting go. Retrieved October 30, 2019, from https://www2.deloitte.com/content/dam/ Deloitte/us/Documents/human-capital/us-consulting-mo-workplace-flexibility-110510.pdf

Deloitte. (n.d.). How corporate real estate can support cost-cutting programs. Retrieved from: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/real-estate/kosteneinsparung_immobilien_en.pdf

Dimache, A and Roche, T. (2015). Implications of the Transition to a Product-Service System on the Business Model. CUAL Repository (Connacht Ulster Alliance Libraries)

Ellen MacArthur Foundation. (n.d.) Bringing office furniture full circle: Ahrend. Retrieved from: https://ellenmacarthurfoundation.org/circular-examples/bringing-office-furniture-full-circle

European Commission. (n.d.). Waste prevention and management. Retrieved from: https://ec.europa.eu/environment/green-growth/waste-prevention-and-management/index_en.htm

Fard Fini, A. A. and Forsythe, P. (2020). Barriers to reusing and recycling office fit-out: an exploratory analysis of demolition processes and product features. Construction Economics and Building, 20:4, 42-62. http://dx.doi. org/10.5130/AJCEB.v20i4.7061

Freymann et al. (2018). Planning for Construction Waste Reduction. USGBC White Paper

Goedkoop, M, J. (1999). Product Service systems, Ecological and Economic Basics (Issue March 1999)

Ghaffar, S H, Burman, M, Brainah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. Journal of Cleaner Production. ScienceDirect. Retrieved from: https://doi.org/10.1016/j.jclepro.2019.118710

Hardie et al. (2011). Waste Minimisation in Office Refurbishment Projects: An Australian

Haynes et al. (2017). Workplace productivity and office type. An evaluation of office occupier differences based on age and gender. Emerald Insight

Haynes et al. (2017a). Corporate real estate asset management: strategy and implementation. Taylor & Francis

Haynes, B. (2012b). Corporate real estate asset management: aligned vision. Researchgate.

Hüer, L. et al. (2018). Impact of Product-Service System on sustainability - A structure literature review. 10th CIRP Conference on Industrial Product-Service Systems, IPS2 2018, 29-31 May 2018, Linköping, Sweden. Elsevier B.V.

Jensen, K. G., Dekker, E., Goa, Q., Lukkes, D., Markus, F., Bohle, M., Asselbergs, T., Luscuere, P., & Parravicini, M. (2019). Up-cycle Amstel.

Jylhä, T. (2019). “Reconceptualising CREM Alignment to Account for Waste” In: Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland, pp. 1197-1206. DOI: https://doi.org/10.24928/2019/0126. Available at: www.iglc.net

Kemperman, A. Appel-Meulenbroek, R. (2019). WORKPLACE NEEDS AND THEIR SUPPORT; ARE MILLENNIALS DIFFERENT FROM OTHER GENERATIONS? TWENTY FIFTH ANNUAL PACIFIC-RIM REAL ESTATE SOCIETY CONFERENCE

Kjaer et al. (2018). Product/Service-Systems for a Circular Economy. The Route to Decoupling Economic Growth from Resource Consumption? Research gate

Kooymans, R. (2000). The outsourcing of corporate real estate management – how do corporate real estate units and outsource service providers view each other and the management issues. Centre for Land Economics and Real Estate Research (CLEARER). School of International Business. University of South Australia

Mestre, A. Cooper, T. (2017) Circular Product Design. A Multiple Loops Life Cycle Design Approach for the Circular Economy, The Design Journal, 20:sup1, S1620-S1635,DOI: 10.1080/14606925.2017.1352686

Meijer, A., 2021. Life Cycle Assessment: Introduction and the four steps of LCA [Lecture]. September 14, 2021

Mitsubishi electric. (n.d.). M-use. Circular elevators: from ownership to use

Omar, A, J. Heywood, C. (2014). Defining a corporate real estate management’s (CREM) brand. Journal of Corporate Real Estate. Emerald Group Publishing Limited Perspective. The Open Waste Management Journal, 2011, 4, 21-27

Parker, D. (2021). To lease, or not to lease? A critical evaluation of Product-Service-System building components in rental housing. Master thesis obtained at TU Delft repository

Pushkar, S. (2015). Application of life cycle assessment to various building lifetime shearing layers: site, structure, skin, services, space, and stuff. ResearchGate

Rampelberg, E. (2021). “Leading a corporate ecological transition”, Field Actions Science Reports [Online]. URL: http://journals.openedition.org/factsreports/6744

Remoy, H. de Jong, P (2018). Sustainable building conversion and issues relating to durability. . In Routledge Handbook of Sustainable Real Estate.

Rombouts, S. (2020). The advantages and challenges of servitization. Retrieved from: https://www.firmhouse.com/blog/the-advantages-and-challenges-of-servitization

Rubin, H. J., & Rubin, I. S. (2005). Qualitative Interviewing: The Art of Hearing Data (2nd ed.). Thousand Oaks, CA: Sage.

Strikwerda, P. (2020). Value in servitization: from customer value to multi-stakeholder value. University of Twente

Stahel, W. (1997). The Functional Economy: Cultural and Organizational Change. The Industrial Green Game. 1997. Pp. 91–100. Washington, DC: National Academy Press.

Brand, S. (1994). How buildings learn.

Tann, D. (2021). Sustainability - The greatest challenge of the construction industry. IGPP. Retrieved from: https://igpp.org.uk/blog/article/sustainability-greatest-challenge-of-construction-industry

Vandermerwe, S. & Rada, J. (1988). Servitization of business: Adding value by adding services. European Management Journal, 6(4), 314–324. https://doi.org/https://doi.org/10.1016/0263-

2373(88)90033-3

Verhoeff, T. (2014). Strategic management of corporate real estate. Optimising juridical-financial flexibility of corporate real estate; the case of Rabo Eigen Steen. Master thesis obtained at TU Delft repository

Wetsteijn, F. (2021). The transition of construction project organisations towards a Circular Economy, by implementing Product-Service Systems. Master thesis obtained at TU Delft repository

Widarta, D. (2021). Exploration towards a Resilient Corporate Real Estate: Re-conceptualisation and Operationalisation in Various Commercial Asset Classes. Master thesis obtained at TU Delft repository

Yin, R.K. (2002) Applications of Case Study Research. Stage Publications, Thousand Oaks, 22-28.

Zwart, T. (2020). PARK 20|20. A Circular Economy Business Model Case. www.r2piproject.eu

8. Appendix

Appendix A: important office component

After the essential office component is identified by conducting three literature reviews, namely Al Horr (2016), Herrick (n.d.), Caki (2021), all office elements are categorized and grouped according to their function to clearly define potential office components that could be possibly provided as PSS.

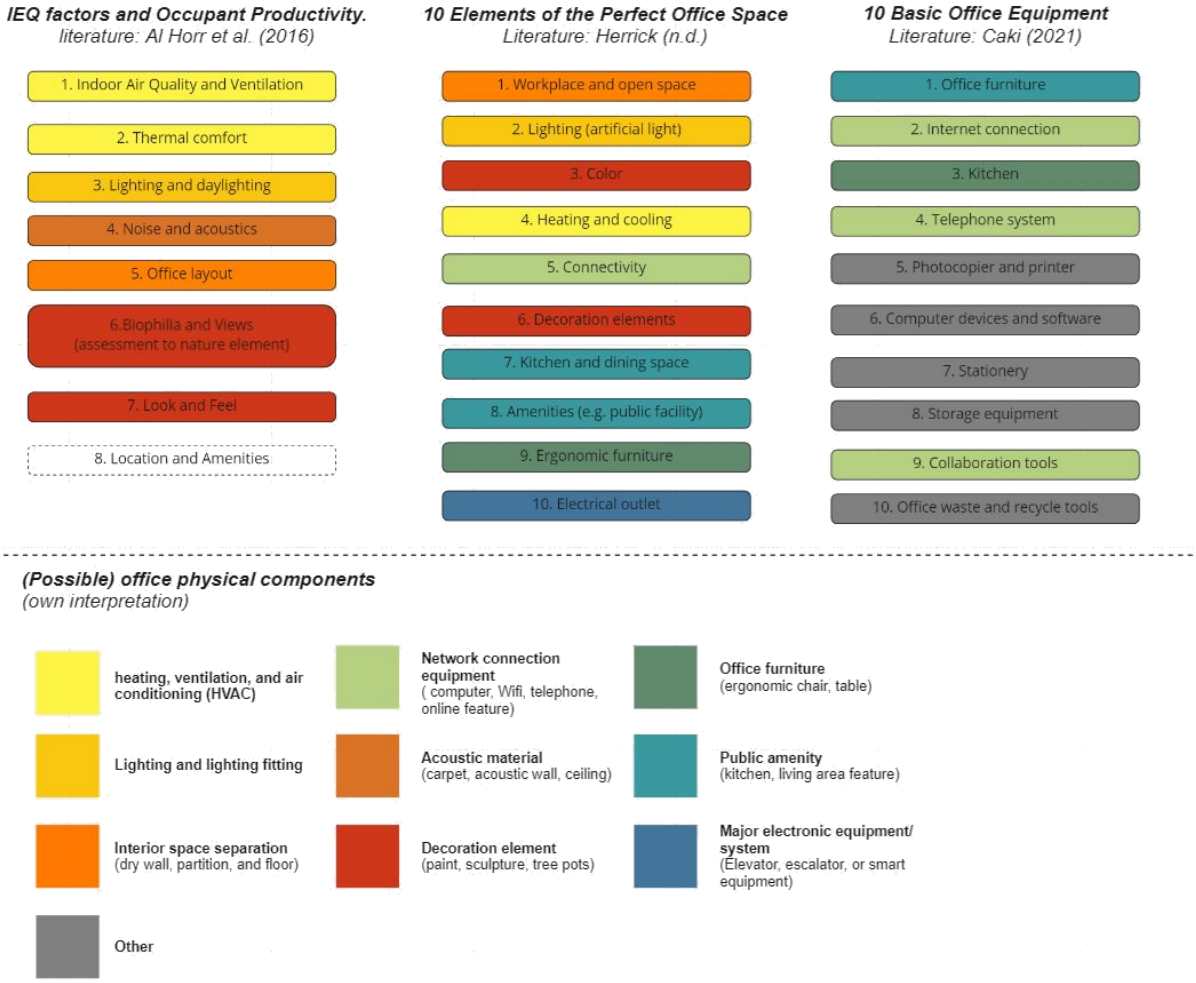

Figure 35: Office component categorization, source: Al Horr (2016), Herrick (n.d.), Caki (2021), (own illustration)

After the office component from the three literature are categorized according to their functionality (see figure 35, office components are classified by using a different color).

Appendix B: Office refurbishment waste

During the office renovation or refurbishment phase, not only tons of construction and demolition waste (C&D waste) are generated but also other solid wastes such as Waste Electrical and Electronic Equipment (WEEE) and other office equipment waste are also ended up in landfills. That amount of solid waste is generally significantly higher than new construction per the same floor area (Hardie, 2011).

Two researchers investigated how the office refurbishment in the central business district (CBD) generated C&D waste in Australia. Both Hardie (2011) and Fard Fini (2020) mentioned that the C&D waste from office refurbishment is increasing these days and it usually ends up in landfills, it is considered one of the serious threats to the biosphere. Their research findings illustrated destinations of C&D waste from office refurbishment, how they were treated, the estimation of waste recovery, and where they went after the refurbishment project was done.

The waste that goes to landfills than 50% of is considered unsustainable, this is aligned with the Eu circular economy action plan which aims to have 50% of products become circular in 2030.

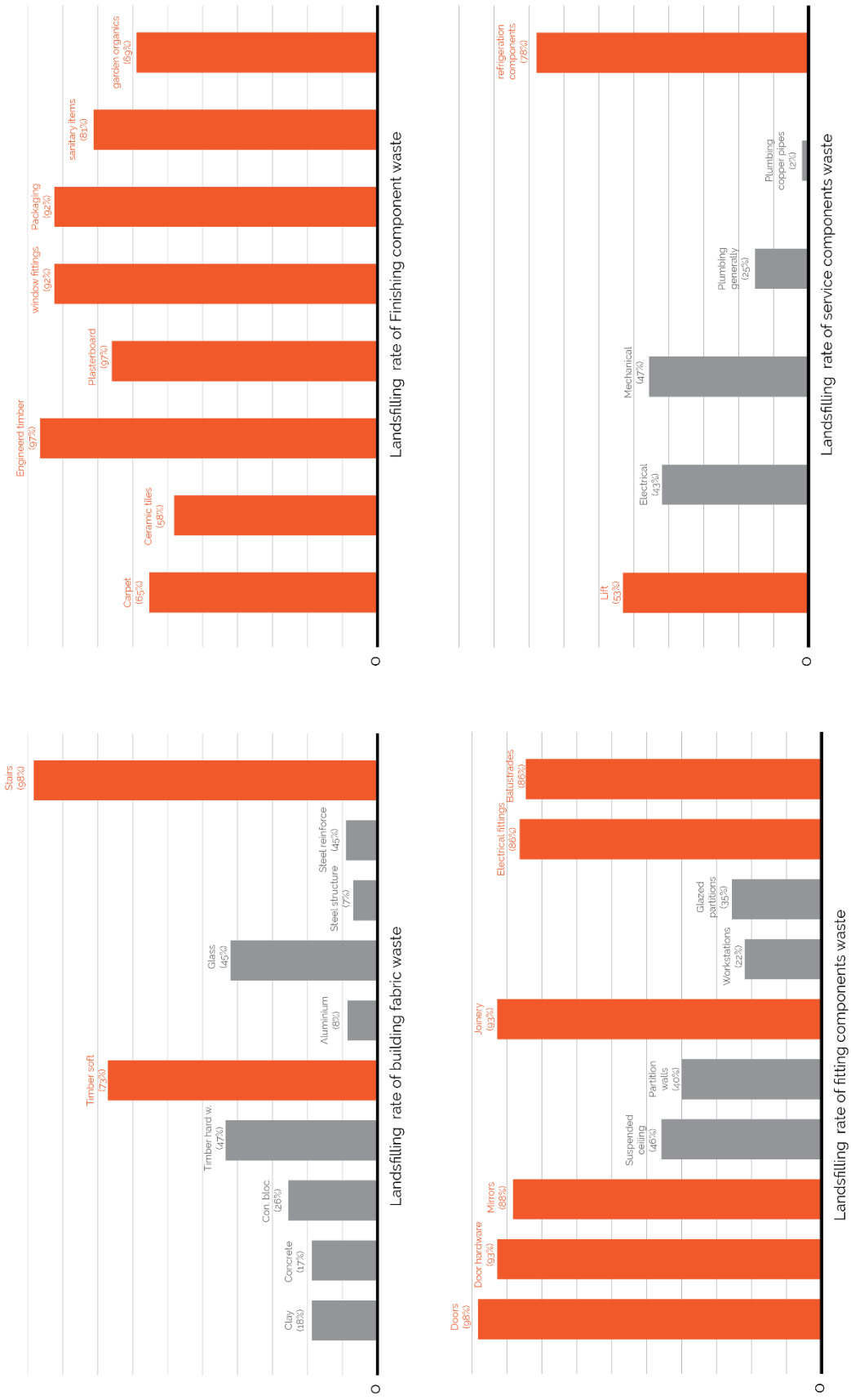

Figure 36: Destination of refurbishment waste by component, source: Hardie (2011), (own illustration)

According to the figures above (figure 36-37), the components that have the least waste recovery rate, which was summarized by Hardie et al (2011), are stairs, engineered timber, window fittings, packaging, doors/ door hardware, joinery, more than 90% of these wastes are landfilled. Meanwhile, the other unsustainable components that have less than a 50% of waste recovery rate include timber softwood, carpet, ceramic tiles, plasterboard, Sanitary items, garden organics, electrical fittings, balustrades, life, and refrigeration components.

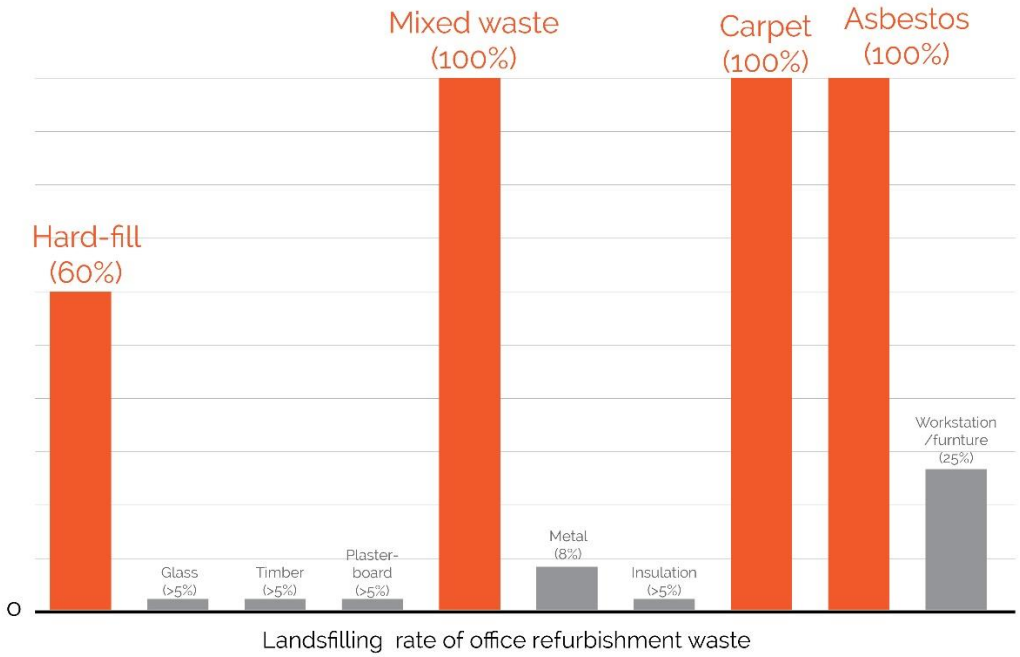

Figure 37: Destination of refurbishment waste by waste category, source: Fard Fini and Forsythe (2020), (own illustration)

The report of Fard Fini and Forsythe (2020) illustrated the destination of office refurbishment waste. Almost 80% of total office refurbishment waste is landfilled while reusing and the recycling rate is 1.6% and 20% accordingly. Three types of waste that are fully ended up in landfills are mixed waste, carpet, and asbestos. Hard-fill waste is partially landfilled, while just only a few amounts of workstation/ furniture and metal are disposed of at the dump site.

Appendix C: Lifespan and material composition of each office component

Categories	Office component	Product lifespan (years)	Waste generation/ recovery rate (in million tonnes)	Product circularity (Material composition and design for recycling)	remark
Interior finishes	Ceiling	20[2]	1. Plaster board (gypsum)Total: 1-2 million tons Waste recovery: **(80-88%)** 2.Wood total: 9-18 million tons Waste recovery: **(25-55%)[4]** 3.Steel total:1-18 million tons Waste recovery: **(80%)**	Asbestos,	Gypsum/ plasterboard in northern Europe in 2015
	Internal partition and drywall	10-30[1, 2]			
	Floor finishes	5-30[2]			The stone floor could last up to 50-75++ years[1]
	Door and hardware	5-7[1]	Waste recovery: **(5%)**4	Ceramic and wooden knob	
	Carpet	5-15[1]	Total: 1.60 million tons Waste recovery: **(>3%)**	bitumen, glue, etc	Also other acoustic material
Service/ MEP	Air conditioner (For commercial building)	10-20[1]	Waste recovery: **(22%)[4]**	Refrigeration components, electrical fitting	
	Boilers, Hot Water	30[1]	Waste recovery: **(50%)[4]**		Considered as mechanical
	Heaters	10-25[1]			
	Lighting fittings	15[2]	Waste recovery: **(55%)[4]**		Considered as electrical
	Sanitary ware	20[2]	Waste recovery: **(75%)[4]**	Coated ceramic	

	Lift and conveyor installations	20[2]	Waste recovery: **(45%)[4]**	Electrical fitting	Other sources range from 10 - 50+ years
Furniture and furnishing element	Loose furniture and fitting	10[2]	Total: 10.78 million tons Waste recovery rate: **(10-20%)***	Joinery, contaminated or hazardous component, glue	In EU28, 2017 Source for waste generation in EU28:
Electronic devices	Communications installations and controls	15[2]	Total: 4.79 million tons Waste recovery: 4.2 million tons **(87%)**	Battery, gold, palladium	In EU28, average from 2010-2018; Trinomics (2020)
Other	Decoration element	N/A	N/A	N/A	
	Kitchen	10*	N/A	Ceramic	*Source: Taylor (2019)

Table 22: Office components analysis, source: Lawrence et al (2010), CLF (2018), EPA (n.d.), Hardie (2011), (own illustration)

Appendix D: The case study building components of Pushkar (2015)

Components	Composite materials (thickness (m)) / (section (m x m))
Foundation: concrete	Concrete length: 14 (0.4 x 0.5), steel
Columns: concrete	Concrete length: 2.6 (0.3 x 0.3), steel
Beams: concrete	Concrete length: 6 (0.2 x 0.35), steel
Partitions: gypsum board	Gypsum board (0.0125), glass wool (0.075), gypsum board (0.0125)
Roof/ceiling: concrete slab	Reinforced concrete (0.14)
Floor coverings: marble	Sand (0.06), mortar (0.02), marble (0.012)
Wall type: concrete	Concrete (0.05, polystyrene (0.03), concrete (0.15)
Wall coverings: stone	Stone (0.02), concrete (0.05), mortar (0.006)

Table 23: Description of building components., source: Pushkar (2015)