A sustainable industrial site redevelopment planning support system

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PROEFSCHRIFT

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Summary

A Sustainable Industrial Site Redevelopment Planning Support System

A significant amount of abandoned or not entirely used industrial sites needs to be redeveloped for a sustainable future. Several studies have been conducted for promoting industrial site redevelopment. However, more studies are needed on developing digital tools for analysing industrial site redevelopment impacts on sustainability. The tools should incorporate multi-scale data and different aspects of sustainability evaluation, to be used in the dynamic land use planning process.

This study proposes a planning support system (Sustainable Industrial Site Redevelopment Planning Support System-SIRPSS), which integrates both industrial site level information and regional level information. Moreover, detailed building information is added into the system so that each site can be better presented and evaluated. This system helps to evaluate the redevelopment scenarios based on sustainable indicators from various aspects. As a result, possible impacts of such a redevelopment process on the site and the whole region sustainability can be evaluated in the early stage of the planning.

SIRPSS is composed of four modules, namely a multi-level data integration module, the land use change simulation module, sustainability evaluation module and a case library. Multi-level data integration module applies building information, geospatial, and demographic, environmental data to find suitable target sites for redevelopment. This data integration module also helps to find similar cases that have been redeveloped to the selected target sites. To find similar cases from the past, a case library which stores industrial site redevelopment experience is constructed. The redeveloped cases' information is embedded in the system as a knowledge database, which is accomplished by applying case-based reasoning. SIRPSS consults existing redevelopment cases to inductively reason possible redevelopment routes (possible redevelopment scenarios and processes) for the selected target site. The references for redevelopment, given back from the system, serve as a starting point for further discussions among stakeholders. The chosen redevelopment scenarios for the target industrial site is the input for the land use change simulation module. This simulation process provides dynamic information regarding physical changes which helps in the sustainability evaluation process. Indicator values generated from the simulated land use modelling process, together with other sustainability indicators are further calculated or analyzed in the sustainability evaluation module, which is used for facilitating to choose a sustainable redevelopment planning scenario.

Several web-based tools are developed to show the applicability of the approach. North Brabant region in the Netherlands is used to test the proposed SIRPSS. Conclusions and future research directions are discussed in the last chapter.

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d: the weighted distance between an existing facility and the desired facility;

ω_i : assigned weight according to the stakeholders' evaluation.

X: the normalised difference between the actual facility value and the desired value for each attribute.

$f_i(x)$:a fuzziness function (Beg & Ashraf, 2009; Chaudhuri & Rosenfeld, 1996; Montes, 2007)

N: number of attributes;

a_i : attribute i value for case a;

b_i : attribute i value for case b;

σ_i : standard deviation for attribute i.

A: =Features with one or two years of industrial land use (and area > 10,000 sq m)

B: =All features with area > 10,000 sq m

Cr,a: =Buffer areas with radius r {100m, 200m, ... 800m} for each $a \in A$

List of abbreviations

GIS: Geographic Information System

BIM: Building Information Modelling

FM: Facility Management

IFC: Industrial Foundation Class

LU: Land Use

ABM: Agent-based Modelling

ANN: Artificial Neutral Networks

AHP: Analytical Hierarchy Process

MCK: Map Comparison Kit

IND: Industrial Site

CA: Cellular Automata

CBR: Case-based Reasoning

PPP: Public-Private Partnership

PSS: Planning Support System

API: Application Programming Interface

Terminology

Several terminologies might be confusing through the dissertation. As a result, they are specifically listed first.

Transition form is the path that an industrial site takes to redevelop. For example, one industrial site transits from industry to retail and the transition form for this site is, therefore, industry to retail.

Chosen strategy is the *transition form* that is selected by the stakeholders for one industrial site.

Vision describes the crucial concerns for each industrial site to be redeveloped, raised by stakeholders. *Visions* can guide the *transition form* selecting process and influence the *chosen strategy*.

*Attribute*s are the critical characteristics of an industrial site such as population density, green space ratio, and other specific, quantifiable reflections of an industrial site.

*Indicator*s are the summed or accumulated value based on various *attribute*s and reflect sustainability aspects from an abstract level, such as safety, accessibility and so on.

Zoning plan is called Bestemmingsplan in Dutch which describes the zoning decision and the decision process for each site.

Zoning documents are the collection of zoning plans.

Zoning map is the map which incorporates all the zoning plans or zoning documents into a geospatial dataset.

Land use map is the shapefiles used for analysing land use information.

Case representation structure is the data modelling structure for representing industrial site redevelopment cases.

Sustainability matrix is the developed sustainability indicator framework which contains multiple indicators that reflect social, environmental, economic and physical aspects on both site and regional level.

CHAPTER 1 INTRODUCTION

In the introduction chapter, the problems of disused industrial sites are explained, with a focus on the Netherlands. In the second part, the efforts researchers have performed to promote sustainable industrial site redevelopment and the challenges they have faced are explained. The objectives for this research are then defined. Based on the objectives, research questions are raised. The outline of this dissertation is presented as a reading guide at the end of this chapter.

1.1 The problem of disused industrial land

The disused industrial land problem is a global concern. For example, local governments in China try to provide industrial land, more than needed, to attract investment and compete with their neighbouring cities (Huang & Du, 2016). Because of this, many of the industrial sites sold are not entirely used or even abandoned. As a result, during the period from 2001 to 2005, 8.78 million square meters of industrial land is in need of redevelopment in China (Xie & Li, 2010). In the Netherlands, the same problem exists. At the beginning of 21st century, the unrealism in new industrial area demand estimation, the financial profitability of developing new industrial sites and mutual competition among municipalities lead to the redundantly large supply of very cheap industrial sites (Olden, 2007; van der Krabben & Buitelaar, 2011). Industrial land users tend to move to a new industrial site than to stay on the same site. According to the Dutch national industrial site database IBIS, 1,052 industrial sites contain signs of obsolescence, equaling 28% of all industrial areas in 2012 (ARCADIS, 2014). The Netherlands is a densely populated country, with 501 people per square kilometres in 2014 (World DataBank, 2014). Land resources are so scarce that it is vital for many cities to reduce the amount of obsolete industrial sites, especially for densely populated ones where opportunities can only be found in a sea of brown spaces, as argued by de Sousa (2014).

The redevelopment of industrial sites can bring quite a lot of benefits as argued by de Sousa and Ghoshal (2012) and Loures and Vaz (2018). Therefore, recently in the Netherlands, more and more attention is put on industrial sites redevelopment to improve city vitality, to reduce increasing pressure on the available land and to stimulate the economy (Louw & Bontekoning, 2007). The new Spatial and Planning Act (Ministerie van Infrastructuur en Milieu, 2011) is enforced in 2008, and it is expected to be integrated into the new Environment and Planning Act (Ministerie van Infrastructuur en Milieu, 2016) in 2019. These new acts aim to simplify procedures and speed up the decision-making process to enable the application of laws that conform to the current regional situation. This new regulation makes industrial site redevelopment process more accessible than before. Regions and municipalities can take more initiatives to redevelop industrial sites. Recently, the relatively heavy redevelopment tasks are located in the provinces of North Brabant, North Holland, South Holland and Gelderland (Nijssen & Kremers, 2013, p. 7).

However, the industrial site redevelopment process still faces stagnation problems. To find the reasons behind the stagnation, Loures (2015) researches 117 case studies from literature to identify the barriers of the reuse of post-industrial sites in urban areas. For the Dutch situation, Glumac *et al.* (2013) have summarised four main reasons causing industrial site redevelopment stagnation, namely large stock with the high vacancy of industrial sites, alternatives to redevelopment, information gap and conflict of interests. Regarding large stock of industrial sites, Olden (2007) explains the reasons behind this in details and calls this a vicious circle of the Dutch industrial area market. Local governments develop new areas to attract more companies which leads to a lack of occupancy on existing ones, resulting in a high vacancy rate. Another reason that causes the redevelopment stagnation is the other possible alternatives such as Greenfield development. It is also imperative to mention the information gap of industrial areas. The property owners are reluctant to reveal contamination potential because of liability fears, and this results in the information gap for local communities to understand the scope and scale of their industrial site situations (Coffin, 2003). Blokhuis (2010) explains the stakeholder's involvement in the decision making of industrial site redevelopment in the Netherlands in more details where the changing roles of stakeholders, the priorities setting, and the negotiation process all lead to the possible stagnation of industrial site redevelopment.

1.2 Research efforts in promoting industrial land redevelopment and challenges

This section firstly explains the research efforts in promoting industrial site redevelopment process. Subsequently, suitable scales and boundaries are identified and the research challenges are discussed.

1.2.1 Promoting industrial site redevelopment research efforts

On the one hand, decision and negotiation theories have been adopted substantially, to promote industrial site redevelopment process. Glumac (2010) examines the impact of making a public-private partnership (PPP) in the industrial site redevelopment process. He also applies game theory and negotiation decision models to analyse PPP in brownfield redevelopment in the Netherlands (Glumac et al., 2016; Glumac et al., 2015). Van der Krabben and Buitelaar (2011) apply institutional, economic theory to analyse the Dutch industrial property market to find favourable interventions from the institutional perspective.

On the other hand, decision support tools are developed to promote sustainable industrial site redevelopment process in the early planning phase. Specifically for selecting suitable industrial sites for redevelopment, Geographic Information System (GIS) is used in integrating various data to prioritise the most suitable sites based on users' preferences (Aktas et al., 2017).

Globally, several European projects are also launched for industrial site redevelopment. HOMBRE project (Beumer, 2014) identifies possible redevelopment technology combinations to reuse brownfields. TIMBRE project (2017) supports end-users in overcoming existing barriers by developing customised problem- and target-oriented packages of technologies, approaches and management tools for mega-site reuse planning and remediation. More general purposed European project also exists such as the German REFINA project which aims at reducing land consumption and encouraging sustainable land management (Viderman, 2015). Redevelopment outcomes are also assessed for different regions based on social, economic and environmental attributes (Jigoria-Oprea & Popa, 2016; Kiss, 2004; Ploegmakers & Beckers, 2015). Industrial land redevelopment policy in Germany and England is assessed (Danielzyk & Wood, 1993; Ganser & Williams, 2007).

1.2.2 Research scales and boundaries

For the Dutch industrial redevelopment process, scholars have concluded that the most suitable and sufficient scale to do research is on the regional level instead of on the local or national level (VROM-raad, 2006). For one thing, spatial-economical processes are better connected on the regional level. For another, the functional and financial aspects of industrial land supply can be tailored most effectively. This claim has also been supported by other researchers as well, such as de Sousa (2017) who compared the North American brownfield redevelopment practice with European practices and claimed that the redevelopment process should not only focuses on site level, but also connected to the regional level. Furthermore, in the industrial sector, reusing existing facilities is a sustainable way of reducing the amount of disused, neglected and abandoned facilities and construction efforts (Conejos et al., 2015; Li & Lui, 2014; Shipley, Utz, & Parsons, 2006). Therefore, facility reuse is getting more attention to seek for a sustainable future. However, a lack of knowledge exists of existing vacant facilities and their potential for meeting the requirements of aspiring future users. Besides industrial site redevelopment, research into facility reuse on an industrial site are not elaborated. Therefore, in this study, the disused industrial sites with existing facilities on them are studied.

Based on the scales, land use management models need to be chosen which help to define boundaries. Van der Krabben and Jakobs (2013) has presented four alternative land development models, i.e. public comprehensive top-down model, public planning-led quasi-market model, private market model, and urban land readjustment model. Public comprehensive top-down model is to implement development program in close relation to city-wide planning goals. Urban land readjustment model is to temporarily transfer property rights of current landowners to a self-organising body for redevelopment practice, and after the redevelopment, the owners regain the property rights. Since not the whole city is going to be redeveloped and this study does not focus on ownership transition, these two models are not considered as suitable for our research. The public planning-led quasi-market model tries to involve private developers to enable a redevelopment program and the private market model specifically focuses on private market initiatives. To find the most suitable sites for redevelopment, both public experts and private parties need to be involved, as argued by Loures and Vaz (2016, 2018). Therefore, these two models are set as the research boundary. They comply with the current industrial site redevelopment practice which promotes private parties' involvement (Glumac et al., 2010, 2016, 2015; Wedding & Crawford-Brown, 2007).

Table 1.2. Land use development models (van der Krabben & Jacobs, 2013)

Land development models	**Definition**	**Main purpose and relation to planning**	**Land assembly**	**Cost recovery and value capturing**
Public planning-led quasi-market model	Public purchase of land (and vacant properties) in a specific area and subsequent sale of that land to the private sector, to enable a (re)development program for that specific area	To achieve a (re)development program for a specific area, sometimes in relation to a city's smart growth or brownfield agenda	Public body acquires the land that is needed for the (future) development of an area	Cost recovery via developer contributions (when a building permit is issued); no value capturing by public authorities
Private market model	Private purchase of land (and vacant properties) in a specific area, to enable a (re)development program for that specific area	To achieve a (re)development program for an area, by zoning regulation	Private sector company acquires land to achieve their own development plans	Cost recovery via developer contributions (when a building permit is issued); no value capturing by public authorities

1.2.3 Research challenges

Despite the efforts mentioned above, there are challenges to be conquered. The following paragraphs explains challenges from four aspects, namely multilevel data integration, learning from the past, industrial land transition impact analysis and holistic sustainability evaluation.

Land use planners from the national and regional level tend to focus on a large scale with a top-down perspective (Needham, 2014). On such a scale, details about individual facilities easily get lost, as information about this is not easily accessible. However, industrial site redevelopment also requires facility information on the sites so that detailed evaluation on building level is achieved and reusing existing facilities could become possible which serve to fulfil sustainable redevelopment purpose. Even though the new trend of building information development makes combining building information with urban geospatial planning not impossible, the integration of building information and GIS data is difficult since information about buildings is mainly based on IFC models (Nagel, Stadler, & Kolbe, 2007) while GIS data are more traditionally defined and data sources are diverse for the facilities and sites. How to integrate multilevel data needs to be studied.

Land use development and redevelopment is an expensive task and has a long-term effect. Therefore, learning from the past is essential. For one thing, the failed experience can be learned. For another, learning from the past can serve as a starting point for innovative designs for the future. How are past cases redeveloped, and what are the impacts of such redevelopment for the site and the whole region? This type of information helps to improve the design process of a new redevelopment site. Currently, in practice, the experience is mainly brought by experts. Computer-aided systems such as expert systems are not widely used in industrial redevelopment practice. However, this should be addressed in research to reduce costs and to improve decision making process.

Governments should be cautious in applying pro-active redevelopment strategies (van der Krabben & Jacobs, 2013) since these redevelopments bring significant environmental, social, economic impacts on the interdependent urban systems. The outcome of a redeveloped project is unique and difficult to foresee, in many aspects, for different contexts and on different scales. In the current practice, the industrial land transition impact analysis is not fully incorporated in redevelopment planning practices. Only limited literature can be found. More detailed land use transition impact analysis should be performed which can help to evaluate possible outcomes for each scenario. A more detailed land use transition analysis is necessary to understand regional specific industrial site redevelopment characteristics, regarding land use compositional changes before and after the redevelopment.

Even though there are many researches on land redevelopment sustainability evaluation on social, environmental and economic aspects, redevelopment impacts on surrounding land use compositions are not yet addressed, except for its impacts on transportation networks (Wang et al., 2015). To be more holistic in sustainability evaluation, besides normally applied environmental, economic and social sustainability indicators, physical sustainaiblity indicators are needed in the evaluation procedures and site and regional level need to be combined. Additionally, sustainability evaluation needs to address regional specific visions by consulting with stakeholders and the assessment needs to be dynamic so that scenarios can be evaluated.

1.3 Research objectives

This research will propose a planning support system (PSS) to support industrial site redevelopment sustainably. The PSS helps in four aspects from the listed challenges in section 1.2.3, namely multilevel data integration, learning from the past, industrial land transition impact analysis and holistic sustainability evaluation.

Possible users of our system are as follows. Government officers who are eager to redevelop industrial areas, urban planners who need to make specific redevelopment plans, private industrial parties who are searching for possible facilities to locate their activities and parties involved in the actual redevelopment process including architectures, civil engineers, project developers and contractors. Inhabitants living in the region should also be consulted for the pre-made designs to get some feedback. The starting point of this research is that stakeholders are willing to start a redevelopment process and are focusing on sustainability. They need to collaborate to specify and narrow down the research interests that are important and supply essential data. More specifically, in this research, a focus is put on reusing existing facilities by matching suitable existing facilities from abandoned industrial sites to the future user needs.

1.4 Research questions

The primary research question of this research is: how to support redeveloping industrial sites with vacant facilities on top within a region in a sustainable way using past experience and holistically assess redevelopment impacts on site and regional sustainability. To answer this primary question, several sub-questions need to be answered.

(1) How to construct computer-aided tools such as a planning support system (PSS) to improve regional planning tasks, regarding industrial site redevelopment? Moreover, what components does it contain?

(2) How to construct a case library which stores past industrial site redevelopment experience?

(3) How to find the most suitable redevelopment sites from a region based on stakeholders' preferences and find similar cases from the library, using both geospatial data and building information?

(4) How to construct a land use simulation model to represent the past land use dynamics and predict future possible land use situations?

(5) How to holistically evaluate the future sustainability on site and regional level which incorporates the new design for industrial site redevelopment?

1.5 Outline of the dissertation

Figure 1.5 presents the outline of this dissertation. The *introduction* chapter firstly explains the problems, research efforts and challenges. Based on this, objectives and questions are raised. The introduction serves as a starting point and basis for the coming chapters. Chapter 2 is a thorough *literature review*. Chapter 3 illustrates the proposed planning support system for sustainable industrial site redevelopment – *SIRPSS*, starting with the theoretical framework. The *data integration* approaches are explained to *integrate multilevel data*. *Case-based reasoning* (CBR) approach used to *learn from the past* and to find suitable redevelopment strategy is explained. A *land use simulation* module is constructed to help *analyse and evaluate the industiral land redevelopment impacts* on site and regional physical sustainaiblity. *Sustainability evaluation* method is presented to *holistically evaluate sustainability*. To illustrate the application of SIRPSS, a case study is performed. Chapter 4 firstly describes the *case area and data* sources. Based on the proposed site selection approaches, suitable site for redevelopment is identified, the *target site*. Constructed case library is presented to match the new redevelopment task with past experience. Based on the experience, the target site is designed; this process is named as *similar cases guided design*. *Regional land use transition* *analysis* is executed so that regional specific *land use change simulation model* can be constructed and used to incorporate new site redevelopment plan into land use simulation process. The land use simulation model helps to evaluate regional sustainability. The guided site design is used to help evaluate site level sustainability. These two aspects of *sustainability evaluation* are illustrated afterwards. The designed scenario for the site is compared with the real design for the *validation* of the proposed PSS. *Conclusions* and *discussion* are presented last.

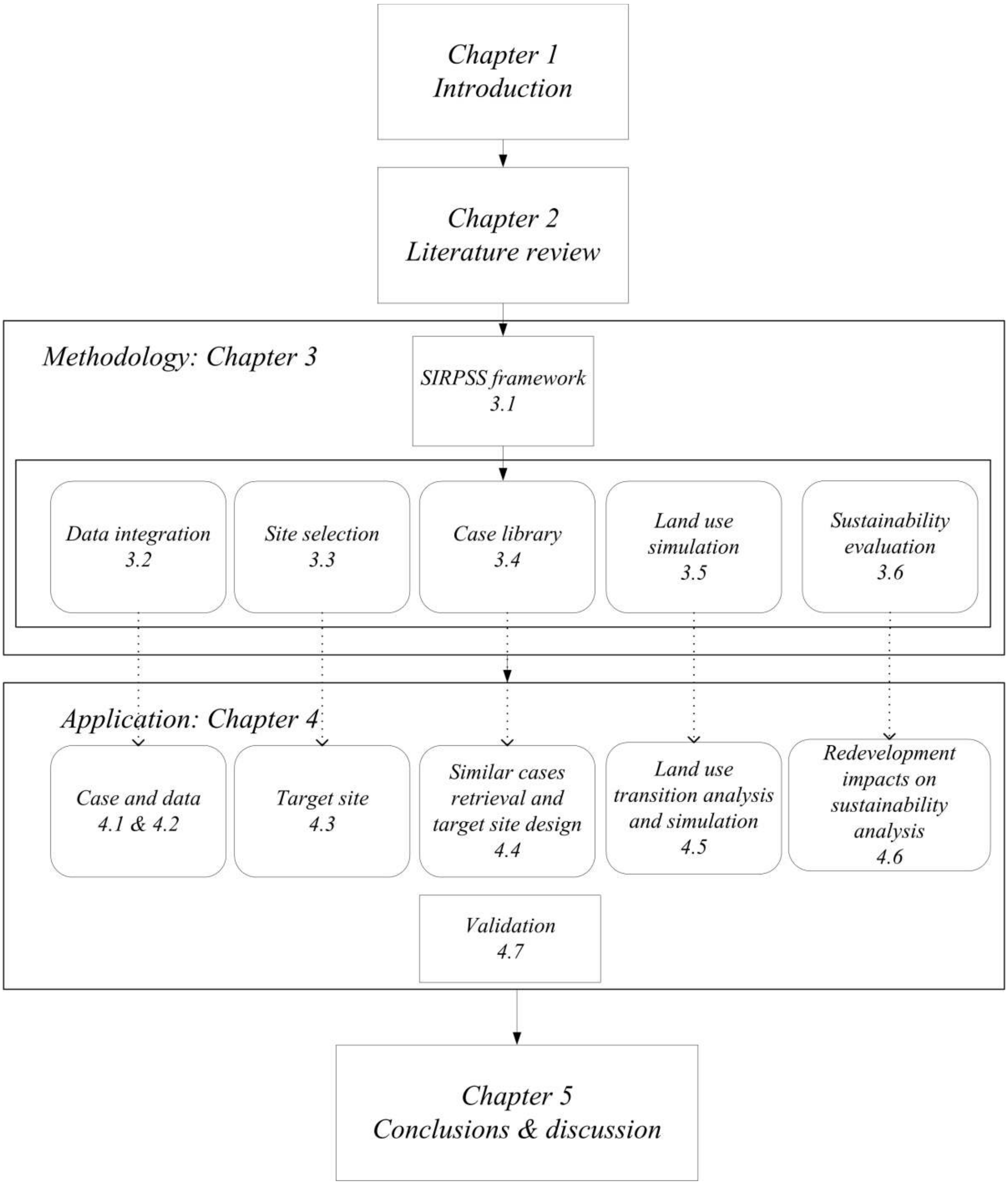

Figure 1.5. Dissertation outline

CHAPTER 2 LITERATURE REVIEW

This chapter presents a thorough review for facilitating industrial site redevelopment process based on the following issues: planning support systems (PSS) for urban planning tasks and essential components for such planning support system including multilevel data integration, case library to learn from the past, industrial land transition impact analysis and modelling, and holistic sustainability evaluation. Each of these aspects is firstly reviewed, and then gaps are found for this research specific target: industrial site redevelopment. Based on these gaps, a requirement summary for such system, named as SIRPSS, is presented.

2.1 Planning support systems[1]

Computer-based systems have the enormous capacity and speed to store, organise, access, process and manage data and are capable of making a number of logical inferences and making the decision making the process transparent (Witlox, 2005). More specifically, the combination of geoscience and computational tools, such as planning support systems, can guide a sustainable urban planning process (Chen et al., 2012). Such tools help to predict future trends in land use changes, to form several possible scenarios and to quantify essential attribute values for possible impact evaluation. It is also beneficial to communicate with stakeholders by making the process more transparent and easily understandable (Petrov, Lavalle & Kasanko, 2009; Pettit, 2005). As a result, the use of a spatial decision support system or planning support systems is advocated to tackle the problem of an unstructured knowledge domain such as for sustainable industrial site redevelopment planning and to assess possible trade-offs between conflicting objectives from various shareholders. The growing interest of using PSSs in urban planning are presented as follows.

Many researches exist in planning support systems for various urban planning problems. Among them, planning support systems for strategic spatial planning, water management, transport networks and tourism planning combined with scenario analysis are common examples (Geertman & Stillwell, 2009). Borgers and Timmermans have proposed decision support and expert system for retail planning in which data are integrated to model consumer

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[1] Modified based on: Wang, T., Han, Q. & de Vries, B. (2018), SIRPSS-Sustainable Industrial Site Redevelopment Planning Support System, F. Dargam et al. (Eds.): ICDSST 2018, LNBIP 313, pp. 1–12, 2018. https://doi.org/10.1007/978-3-319-90315-6_1

choice behaviour and evaluate alternative retail plans (Borgers & Timmermans, 1991). LandSys is an integration PSS that combines agent-based modelling and cellular automata model for transportation demand modelling and analysis (Zhao & Peng, 2012). Environment Explorer is a spatial support system for integrated assessment of social-economic and environmental policies in the Netherlands which combines several sub-systems from a macro level (Engelen, White & Nijs, 2003). RULES is a GIS-based PSS for rural land use allocation which uses hierarchical optimisation, ideal point analysis and an algorithm based on simulated annealing. Alternative land use plans can be generated based on different stakeholders' perspectives (Santé-Riveira, Crecente-Maseda & Miranda-Barrós, 2008). Schreinemachers and Berger (2011) have developed an agent-based software package, MP-MAS, to simulate farm decision-making in agricultural systems. Stelzenmüller *et al.* (2012) has provided a review of tools to support marine spatial planning. Zolnik *et al*. (2010) has presented an example of PSS to help planning public facilities co-locating planning to reduce resource waste and increase efficiency, increase synergy of services and enhance the sense of community. The BRIDGE project has presented a PSS that systematically integrates urban metabolism components into impact assessment processes to accurately quantify the potential effects of proposed planning interventions (González et al., 2013). Dhaka Metropolitan Development Planning Support System (DMDPSS) is proposed (Roy, 2009), to evaluate sustainable urbanization mitigation and adaptation options in fast-growing cities. As has been illustrated, PSSs are used in various planning practices for different domains.

For specific industrial land planning issues, not many references can be found. Limited references are listed here. There are attempts for industrial site selection (Wang et al., 2013; Witlox & Timmermans, 2000) and risk management for contaminated sites and hazardous industry land (Cameron, 2000; Carlon et al., 2008; Sejwal, Jangra & Sangwan, 2012; Zabeo et al., 2011). There are attempts for planning sustainable industrial area and modelling industrial land redevelopment collaboration process (Blokhuis et al., 2012; Glumac, 2012; Ruiz et al., 2012). Several researchers have identified the most important attributes for the selection of industrial redevelopment areas and the appraisal for redevelopment plans (Alberini et al., 2005; Blokhuis, 2010; Glumac, 2012). Cheng *et al.* (2011) have presented two frameworks for identifying potential brownfields and establishing priorities for redevelopment, while Ruiz *et al.* (2012) have proposed a PSS based on GIS platform to evaluate industrial area location suitability using sustainability criteria. Wang *et al.* (2013) have presented a GIS-based decision support tool (LUDS) to quantitatively assess land use suitability for site redevelopment, which also combines multi-criterion analysis and Analytical Hierarchy Process (AHP) (Saaty, 2008) method. Ruiz *et al.* (2012) have presented a spatial decision support system based on GIS platform to plan sustainable industrial sites in Northern Spain, which highly rely on stakeholders' inputs and available data to evaluate indicators from social-economical, physical-environmental, infrastructure and urban development aspects.

Even though existing study identify the causes and effects of industrial site problems, proposes strategic and management frameworks, and present IT technique solutions, these researches have gaps from four aspects. Firstly, they are mainly on a theoretical level regarding process modelling with stakeholders. Secondly, these PSSs are mainly used for site selection or redevelopment proposal assessment, thus are mainly used for the pre-planning phase. For sustainable redevelopment planning, the actual redevelopment process, so to say the life cycle analysis of industrial areas is also essential which considers not only the starting of a project but also the execution and the maintenance of the project, as concluded by Yi *et al.* (2007) that it is required to include life cycle analysis to model the dynamics of the system, especially for land use study and a dynamic update needs to be possible for a long-time planning practice. Thirdly, the redevelopment effect of one site on the whole region is not yet addressed to pursue a more balanced strategy, as argued by Loiseau *et al.* (2012). Lastly, despite the potential of PSSs, several bottlenecks that cause the limited use of PSSs in planning practices are found. These bottlenecks include not only lack of awareness, lack of experience, and lack of general intention to use PSS among users of PSSs in spatial planning practice (Vonk, Geertman, & Schot, 2005), but also those in power are afraid to lose their position to instruments they cannot control (Vonk, Geertman & Schot., 2007).

In this research, the following gaps are going to be targeted. Planning support systems are to be developed which help to present possible scenarios based on various planning strategies in the early phase by integrating various types of data from multiscale and avoid planning failures from the planning phase and improve the stakeholder communication processes for the whole life cycle. Visualization and public participatory planning should also become possible to make the application not purely theoretical.

2.2 Multilevel data integration – BIM and GIS[2]

This section first explains the significance of building information and the integration of BIM data and GIS data to design industrial sites with a focus on facility reuse for a sustainable future. It explains explicitly the data formats and possible sources from both GIS and BIM sides for facility reuse, based on a thorough literature review.

2.2.1 The significance of building information and data integration for facility reuse

Private developers might be interested in several sites, and they would like to collaborate with the government to find the most suitable one for redevelopment (Bullen, 2004; Love & Bullen, 2011). For a sustainable future, facility reuse needs to be put on the agenda. Facility reuse can serve as the primary driver for land use redevelopment and allow private parties to state their interest and their participation can democratise the planning process (Elrod & Fortenberry, 2017; Love & Bullen, 2011; Tan, Shuai, & Wang, 2018). Furthermore, with detailed building information models, life cycle analysis and management can be achieved since this type of information helps to maintain the facilities and evaluate the life cycle situations in different stages (Tan, Shuai, & Wang, 2018; Wang & Krijnen, 2014). As a result, the whole life cycle asset management is possible. Simulation of other vital aspects could also be achieved using building information models on the detailed building level, such as fire-fighting simulations (Chen et al., 2014) . Besides these advantages, many facilities are in historic areas. These buildings can often be listed as a heritage and have a specific character. The buildings can be very attractive to certain types of customers for specific uses, such as the case of Lichttoren in Eindhoven which is transformed from old Philips factory into the luxury residential building (Wikipedia, 2015). Last but not least, it is also claimed that reusing existing facilities saves 10%-12% investment compared with building new ones (Shipley, Utz, & Parsons, 2006).

Recently, more and more detailed building information models become available, due to technological advances as well as legislation required to get building permits (Das et al., 2011). The availability of these models enables new methods to stimulate facility reuse. An interesting case study using BIM techniques and multi-criteria study to reuse facilities is presented by Pavlovskis, Antucheviciene and Migilinskas (2017). Research has been conducted on the usage of Geographic Information System (GIS), Building Information Modelling (BIM) and their integration mainly in the domain of Facility Management (FM). Rich and Davis (2010) provide

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[2] Modified based on: Wang, T., Krijnen, T.F. & de Vries, B. (2016). Combining GIS and BIM for facility reuse - a profiling approach. Research in Urbanism Series, 4, 185-204. DOI: http://dx.doi.org/10.7480/rius.4.824

a detailed overview of the application of GIS for facility management and the integration with other applications, including BIM. They conclude that in the field of facility management, combining GIS and BIM is helpful to ensure requirements are met, and data that is needed at various stages of FM is captured.

2.2.2 Data formats and theoretical background

The Industry Foundation Classes (IFC) file format is a commonly used standard in the domain of BIM. It is spearheaded by the buildingSMART consortium (buildingSMART consortium, 2014) and has been ratified as an ISO standard (ISO, 2013). IFC describes a building model as an assembly of building products, in which the products are composed of geometrical representations, semantic information stored as key-value properties and relational information about decomposition and topological adjacency. IFC is based on STEP ("STEP ISO 10303," 2018) and has an EXPRESS schema ("EXPRESS," 2018) definition, which defines the entities along with their attributes and relationships that constitute a valid IFC file. IFC files are stored as either ASCII (Wikipedia, 2018) or XML ("XML tutorial," 2018) files and are therefore human readable. Besides the definition of the schema, buildingSMART also standardises on sets of properties, which are plain text, to be used to cover common use cases. Other formats exist, for example, gbXML (gbXML.org, 2014) or proprietary file formats which are native to commercial BIM applications.

Conversely, in the GIS domain, shapefiles (ESRI, 1998) are a commonly used option for describing vector features, one example is shown in Figure 2.2.2. This "de facto" standard has organically grown out of an initially proprietary format. Such a GIS database consists of a set of binary files. The geometrical information itself is separated by several files based on their types or layers. These geometrical entries define the location or perimeter of a feature in the world. Metadata records are stored in separate files that provide the meaning for these features.

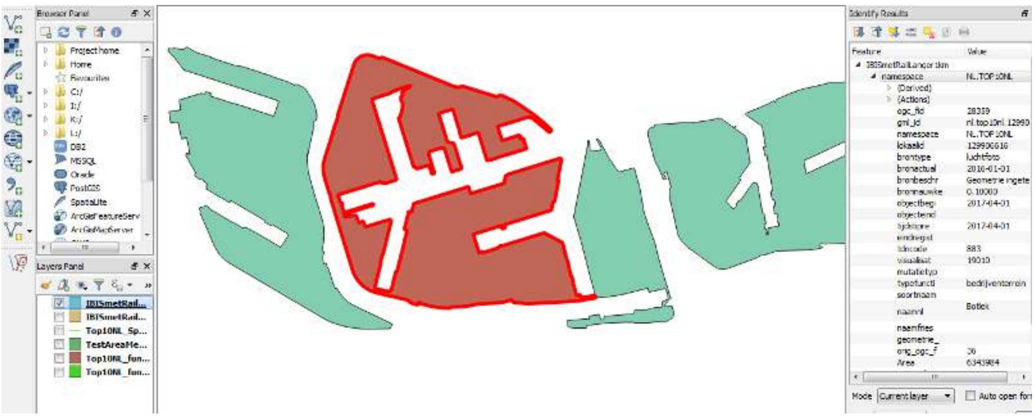

Figure 2.2.2 Illustration example of a Shapefile with attributes

In addition, hybrid formats intended for use on an intermediate scale exist. For example, the CityGML format (Open Geospatial Consortium, 2012), which is an XML based standard led by the OGC (Open Geospatial Consortium, 2014). It lacks the semantic, topological and parametric richness to convey constructed documentation as can be found in an IFC document, but is suitable for documenting urban environments in three dimensions. The use of CityGML is currently not used, as public datasets on an urban scale are not available within this research. The translation from IFC to CityGML is discussed in (Isikdag & Zlatanova, 2009; Nagel,et al., 2007). On a building scale, the expressiveness of IFC is richer than CityGML in most aspects; such a translation to a large extent boils down to converting the solid volume representation in IFC into merely the visible surfaces for use in CityGML to map the classes. Conversion the other way around is more difficult due to richer semantics required to constitute a meaningful IFC, as has also been reported by (de Laat & van Berlo, 2011; EI-Mekawy, Ostman, & Hijazi, 2012; Isikdag & Zlatanova, 2009) and due to lack of solid volumes.

2.2.3 Important attributes for facility reuse and possible data sources

Important data and possible sources from both GIS and BIM aspects for facility reuse and industrial site redevelopment are identified based on a thorough literature review. A detailed list is presented in Appendix A. They are categorised into building-level attributes, building plot and geospatial characteristics and demographic properties. The identification of the attributes is based on the findings by several scholars (Bottom, McGreal, & Heaney, 1998; Geraedts & Voort, 2003; Glumac, 2012; Korteweg, 2002; Remøy, 2010; Stichting Real Estate Norm Nederland, 1992; Voordt & Wegen, 2005). The attributes are classified according to their level of measurement, whether they are numeric or nominal. Figure 2.2.3 illustrates one of these attributes for two distinct facilities which shows the openness of architectural space, to be extracted from the BIM. The architectural openness can be seen as a measure for the flexibility of the facility. Data sources for Dutch cases and references to the tools for automatically extracting or calculating these attributes are also provided in Appendix A. For implementation into other target areas, this list of attributes will likely have to be tailored to the new area.

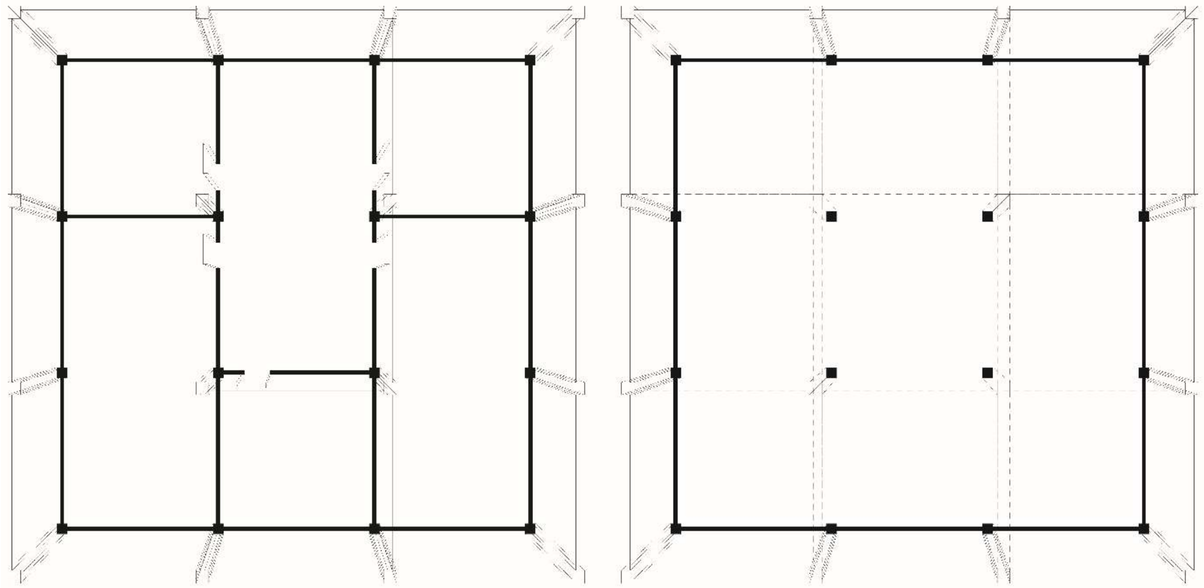

Figure 2.3.3.1. Illustration example of openness attribute from two facilities

2.2.4 BIM and GIS for facility reuse gaps

Three gaps for facility reuse using BIM and GIS are identified. Firstly, even though GIS and BIM analysis can help find a suitable location for a new facility (Abudei, Abdel Moneim, & Farrag, 2015; Panichelli & Gnansounou, 2008; Rikalovic, Cosic, & Lazarevic, 2014; Zhang, Johnson, & Sutherland, 2011) and more building models are getting available, BIM models for existing buildings are limited (Volk, Stengel, & Schultmann, 2014), which can be attributed to the fact that only recently BIM technology has become more popular. Secondly, for facility reuse, research on BIM or GIS or their integration is limited. In this domain, the integration of GIS and BIM is of importance to connect geospatial information to detailed building-level information to make informed decisions about the reuse suitability and transition possibilities of existing vacant facilities. For facility reuse, the emphasis not only lies on the physical facilities themselves. Also, the surroundings play a crucial role in the decision processes of the stakeholders involved. Notable exceptions include attempts to integrate BIM and GIS for emergency response (Lee et al., 2013) and lifecycle management of a facility and its surroundings (Mignard & Nicolle, 2014; Shen, Han, & Xue, 2012). Thirdly, an IFC file has a default decomposition structure, which starts with a project and descends into a site, a building, individual building stories, and down to individual building elements. Typically, a building does not have a geometrical representation of its own but is geometrically defined as the composition of its elements. In the GIS domain, the building footprint is represented as a polygonal boundary. Associated attributes can be applied such as the building height or its use.

In IFC the site can have a geometrical representation, but there is no guarantee that it is aligned with any of the footprints in the GIS system or the cadastral records. The IFC standard primarily intends the site to be used only for construction purposes.

In this research, it is assumed that the successful selection of a facility for reuse is more likely when geospatial information and building information are both considered. This research is going to propose an approach to combine this two data sources' information for facility reuse, considering the limitations of BIM models regarding quantity and quality.

2.3 Case-based reasoning[3]

For a complex urban planning task, it is vital to prevent unfavorable decisions in the early stage so that costs can be minimized to a large extent. Learning from experience to support future site design can minimize the unfordable costs by adjusting redevelopment strategies based on successful and unsuccessful experience (Cinar, 2009). Case-based reasoning (CBR) provides approaches to solve problematic situations at hand by finding similar cases from the past. In this way, learning from the past can be achieved. A case is a contextualized piece of knowledge representing an experience that teaches a fundamental lesson to archive the goal of the reasoner, which generally contains a problem description and the solution to the problem (Biswas, Sinha, & Purkayastha, 2014). CBR allows incremental and sustained learning by retaining solutions each time a problem has been solved, successfully or unsuccessfully. Therefore, CBR can be of practical help in the urban planning field (Aamodt & Plaza, 1994). Yeh and Shi (1999) claim that CBR can be used to overcome the knowledge elicitation and black-box operation problems of rule-based and model-based knowledge systems and they give an overview of CBR's potential for urban planning tasks. The CBR approach has been formalized into four steps: retrieve, reuse, revise and retain as stated by (Aamodt & Plaza, 1994). The first step supports to find similar cases in the constructed case base. The second and third steps are to check whether users can directly reuse the strategies from the past or whether they need to revise the strategies before applying them. In the last step, the new case and its solutions are stored or retained in the case base for future use (Aamodt & Plaza, 1994; Kolodner, 1993; Slade, 1991). For different purposes and domains, these four steps are performed selectively.

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[3] Modified based on: Wang, T., Han, Q. & de Vries, B. (2017). Sustainable industrial site redevelopment planning support: a case-based reasoning approach. International Journal of E-Planning Research, 6(2):3 DOI: 10.4018/IJEPR.2017040103

In most cases, CBR is mainly used as a case retrieval system because the revised process is not easy to automate (Biswas, Sinha, & Purkayastha, 2014).

CBR has been applied in many domains. In the drilling industry, CBR supports to improve the drilling planning and operation. For example, possible risks can be identified from past experiences that are like the current planning task. An overview paper on the use of CBR in the drilling industry can be found in (Shokouhi, Skalle, & Aamodt, 2014). CBR has also been widely applied in weather forecast applications, in combination with algorithms such as fuzzy set theory and fuzzy logic for more accurate prediction (Riordan & Hansen, 2002). In this domain, historical weather conditions are stored in the case base for future prediction activities to consult and to retrieve similar cases. Also, CBR has been proven to be an appropriate method to explore in a medical context where symptoms represent the problem, and diagnosis and treatment represent the solution, as has been stated (Begum et al., 2011). For example, Neshat *et al.* (2012) have proposed a method using CBR to diagnose hepatitis disease with an accuracy of 93.25%.

CBR applications in the urban planning field are mainly combined with geographic information systems (GIS), in which planning regions and their attributes represent the case at hand. A system is proposed to assist planners in dealing with planning applications in development control in Hong Kong. It integrates a CBR shell and GIS package (Yeh & Shi, 2003). In another research, CBR software jCOLIBRI 1 and GIS data are applied to support the planning process in the region of Çeşme Peninsula (Cinar, 2009). Furthermore, CBR has been applied in cellular automata models to improve land use change simulation results (Li & Liu, 2006). The discussed applications determine possible outcomes based on retrieved solutions of similar cases. Their primary focus is on the retrieval of similar cases from the library. The process of revise in the CBR model is not typically applied. It can be problematic in the urban planning field to learn from experience, because of the complicating factors involved in planning tasks, including, but not limited to, expectations from various stakeholders, a significant amount of investment and complex impacts on the environment, society and economy (Yeh & Shi, 1999).

Similarity assessment is especially emphasized because of its importance for finding relevant cases (Cunningham, 2009; De Mantaras et al., 2005; Wess, Althoff, & Derwand, 1994). To determine the similarity between cases, it is important to describe the cases in the same "language". In the CBR field, this means the same case representation structure. The case representation structure determines the way in which problems and solutions are encoded. A large variety of representation formalisms have been proposed which can be classified into four categories, namely feature vector cases, structured cases, textual cases and specialized representation for specific tasks (Bergmann, Kolodner, & Plaza, 2005; Shaker & Elmogy, 2015). Firstly, feature vector cases are represented as attribute-value pairs, and these attributes have no correlation or hierarchy. Case similarity is based on the sum weighted attribute values of a new case and past cases. Secondly, structured cases, or called relational cases are clusters of relations between the kinds of elementary objects that comprise them. This type of representation is usually developed around a frame-based formalism where each frame has its own name and a set of attributes. A frame can represent a case itself, and each frame slot is a feature which may contain a primitive value or a pointer to another frame. As a result, semantic relationships are possible for the cases represented in this way. Hierarchy of cases, therefore, can be formed. Moreover, domain knowledge can be integrated into the case representation by a sort of hierarchy and "notion of terms". For example, in the urban planning field, attributes to describe a site's physical conditions can be grouped as one "slot" for a "frame" while attributes for demographic conditions can be classified into another "slot". In this type of case representation, case similarity is determined based on relations. Thirdly, another type of case representation structure is called textual representation where easy exploitation of experiences captured in documents is possible. In the urban planning field, zoning plans contain much richer information than simple attribute values and term categorization. For example, the rationale behind each decision made, the specific policy concerns and process are recorded in the zoning plans. Lastly, more complex case representations exist such as the hierarchical case which uses multiple representations at different levels of abstraction. A new case is matched to the existing cases based on abstraction from appropriate levels. For example, a new site will be redeveloped for a better living environment for older people, as a result; only cases that have "healthy living for older people" tag or term should be consulted for matching search. Labelling reduces the searching time and matching intensity.

Even though CBR can be of practical help in the urban planning field, compared to other domains, the application of CBR in the urban planning field is limited (Yeh & Shi, 1999). Moreover, as stated in section 1.2, redevelopment of industrial sites can be either led by government or by private parties. These two parties should collaborate to design a better, more sustainable future for the site and the region to accelerate the process through transparent discussions (Yeh & Shi, 1999). However, no approaches which combine top-down governmental supply of industrial sites with bottom-up specific requirements based on private developers, referencing past experience have been proposed.

In this research, CBR is going to be implemented in a GIS based planning support system environment to fill three gaps: experience should be learned and linked to the current new case; data from the past should be reused and referenced; public parties and private parties' interests should be matched in a transparent discussion process.

2.4 Industrial land use transition impact analysis and modelling

For this research, the scope is on industrial land use analysis and modelling. The first part is about the industrial land use transition impact analysis review and the second part is about the land use modelling review to serve land use transition impact analysis. Based on these two aspects, gaps are identified.

2.4.1 Industrial land use transition impact analysis[4]

Research has already been carried out which analyses the Dutch industrial land market, especially from a social, economic or political perspective (Blokhuis et al., 2012; Glumac et al., 2016). There is also quite voluminous literature on the impact of (derelict) industrial sites and brownfields on surrounding property values, such as the Dutch North Brabant case by de Vor & de Groot (2011). An American case is applied to illustrate the impacts of industrial site redevelopment on neighbouring housing prices, regarding the economic aspect (Woo & Lee, 2016). Similarly, 36 redeveloped industrial heritage sites in the Netherlands are studied to evaluate whether the redevelopment has caused positive external effects by the changed nearby residential area housing prices (van Duijn, Rouwendal, & Boersema, 2016). Another example from a Hong Kong case on the building level reveals that there are some positive indications that property values may be enhanced after the revitalisation of old industrial buildings (Mesthrige, Wong, & Yuk, 2018). Wcisło *et al.* (2016) illustrate the role of human health risk assessment (social aspect) in contaminated industrial site redevelopment planning process, using a case from Spain. A GIS-based tool called STEPP (Carsjens & Ligtenberg, 2007) is developed to support local authorities in evaluating industrial site redevelopment impact changes regarding environmental issues such as noise, smell, dust and danger, using a Dutch case from Nijmegen. Energy and climate change evaluation is a hot topic in the environmental

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[4] Modified based on: Wang, T., Han, Q. & Vries, de, B. (2014). Land use change modeling and calibration through transformation potential analysis. 12th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, 25-27 August 2014, Eindhoven, the Netherlands. And Kazak, J., Wang, T. & Szewrański, S. (2015). Analysis of land use transformation potential in spatial management. Real Estate Management and Valuation, 23(1), 5-14. DOI: https://doi.org/10.1515/remav-2015-0001

assessment for industrial site redevelopment, both on project level (Hartmann et al., 2014) and on a city level (Hou et al., 2018; Koch et al., 2018). For more holistic assessment of industrial site redevelopment on project level, see (Zhu et al., 2015) and on building level, see (Chan, Cheung, & Wong, 2015). The Dutch Environmental Assessment Agency has published a report about business zone redevelopment conditions, wherein the most influential attributes that determine the transition possibilities are identified (Renes et al., 2009). IBIS data, which monitors the Dutch business land, concerning working locations (ARCADIS, 2014), is used.

Even though these are fascinating researches and detailed analysis, limitations exist. Generally, the outcome of a redeveloped project is unique and difficult to foresee, in many aspects, for different contexts and on different scales, as shown in the literature review. For the Dutch cases, the business zones include not only industrial sites, but also harbour areas and offices. The transition forms are only limited to revitalisation, to housing and other functions. Besides these two points, the analysis is based overall national database and the scale is on site level, where the characteristics of a specific region are not identified. Furthermore, it is also important to evaluate the impacts of a redevelopment plan on the future land use compositions- physical impacts but this has not yet received much attention. As argued by Banzhaf *et al.* (2017), questions such as “what role do specific land-use types have under certain conditions?” and “how will they be changing?” can guide us in land use planning. The insight of land use transition impacts on surrounding land uses can help to evaluate possible future scenarios by combining physical land use conditions with social, economic and environmental aspects of assessment. Physical land use conditions also provide more insights to environmental, social and economic assessment since human being activities are conducted in the physical environment.

In this research, the gaps of industrial land transition impact analysis with a focus on physical surroundings are going to be addressed for a region since each region has its own characteristics regarding land use transitions.

2.4.2 Land use change models[5]

Land use change modelling is typically applied to support the analysis of the causes and consequences of land use changes to better understand the functioning of the land use sytem and to support land use planning and policy (Verburg et al., 2004). There are many models

[5] Modified based on: Wang, T., Han, Q. & de Vries, B. (2017), A semi-automatic neighborhood rule discovery approach, Applied Geography, Vol 88, pp 73-83, ISSN 0143-6228, DOI: 10.1016/j.apgeog.2017.08.014

available for land use change modelling, Noszczyk has provided a detailed review of existing land use change modelling approaches. Six different types of land use change models are compared for their advantages and limitations, namely agent-based models, artificial neural networks, cellular automata, economics-based models, Markov chains and models based on statistical analysis (Noszczyk, 2018).

Agent-based modelling (ABM) is a "computerized simulation of a number of decision-makers (agents), which interact through prescribed rules" (Farmer & Foley, 2009) and an ABM for land use change has two components, i.e. a map of the area of interest and a model with agents representing human decision-making (van Schrojenstein Lantman, et al., 2011). ABM is getting more attention for land use change modeling because land use change is a complex process, which involves actors on various social and spatial levels and ABM can model these actors with different characteristics, beliefs and knowledge (Murray-Rust et al., 2014; Valbuena, et al., 2010). However, their use is limited because of the complexity involved and some important details lost due to the nature of the analysis applied since they focus on the most obvious and easily quantifiable aspects of land use (Dang & Kawasaki, 2016). Some other limitations are as follows: large data input is needed, description of decision-making rules for agents is difficult and controversial, model results are difficult to be analyzed and the correctness of the model is difficult to be verified (Noszczyk, 2018).

Artificial neural networks (ANN) aims to produce a machine capable of human-like mathematical logic (Basse, et al., 2014) and ANN have been applied for land use modelling by assuming a relation between past and future land use (van Schrojenstein Lantman et al., 2011). ANN becomes popular in land use modelling thanks to their ability to learn and mimic complex phenomena by mathematical functions behind and it could be used for facilitating the development of a complex land use model such as to optimize the configuration of an area where various parameters based on empirical data are needed (Basse et al., 2014). However, it is time-consuming and complex to build. Furthermore, it is data-intensive and the transition rules calculated are hidden to the user which results in a "black box" (Noszczyk, 2018).

Cellular automata (CA) are based on an analysis of the spatial structure of land use and land use can be explained by the current state of a cell and changes in its surroundings. CA takes spatial interactions and temporal dynamics explicitly in the decision rules which describe the conversion probability (Verburg et al. 2004). Cellular Automata (CA) models have been used in many applications for their simplicity and flexibility (Barredo, et al,, 2003; Batty, Xie, & Sun, 1999; Engelen et al., 1995; Li & Yeh, 2000; Stevens, Dragicevic, & Rothley, 2007;White

& Engelen, 1997; Wu & Webster, 1998). In recent years, it has become one of the most popular modelling approaches for land use change simulation (Lagarias, 2012; van Vliet, White, & Dragicevic, 2009; White et al., 1997; White & Engelen, 1993) and has proven to be efficient for spatial land use change simulation. Furthermore, CA is a spatial oriented method and compatible with raster data, and could be implemented in GIS for visualization purpose. Clear transition rules can be defined and less data are needed as opposed to ANN and the results are illustrative. However, CA fails to take human decisions that influence the spread of the build-up areas into consideration (Noszczyk, 2018).

Economic-based models of land use changes are based on the principle of basic land usefulness in monetary terms or others and assume that landowners use them in a manner that maximizes their usefulness and expected profits (Dang & Kawasaki, 2016). They can be used on various scales and can facilitate direct use of input from external models in a coherent manner. However, since they are not spatial models, they fail to take the geographical location into account to the full extent and they neglect other factors driving land use changes except economy (Noszczyk, 2018; Verburg, de Groot, & Veldkamp, 2003).

Markov chains technique uses matrices to represent changes between land use categories and is broadly used to forecast future use changes based on previous changes (Guan, et al., 2008; Kumar, Radhakrishnan, & Mathew, 2014; Muller & Middleton, 1994). Markov chain is simple to apply but able to describe complex and long-term process of land use conversion in terms of simple transition probabilities and it is one of the most effective methods for estimating transition of each type of land use (Kumar, Radhakrishnan, & Mathew, 2014). However, this technique neglects the spatial aspect of land use transition, i.e., no information on the spatial distribution of changes is provided (Noszczyk, 2018).

Statistical methods use mathematical relationships to link land use changes with various variables such as population changes, economic transitions and so on. Depends on the relations of these variables to land use changes, multiple statistical methods can be used, such as linear, nonlinear, binominal logit, multinomial logit models and logistic regression models (Lesschen, Verburg, & Staal, 2005). Statistical models can help to detect and analyze trends and facilitate understanding of the model behaviors of a natural system. However, a lot of data is needed (Noszczyk, 2018) and statistical models often assume that land use change processes are stationary (Veldkamp & Lambin, 2001), i.e. all parameters of the process are time-invariant or if both the mean value and the autocorrelation function remain constant in time (Karlin & Taylor, 1975) .

This research focuses on understanding land use changes impacts on surroundings and the surrounding land uses influences on land use transitions. Therefore, spatial information is necessary. Furthermore, since land use system is a complex system, in this study, the focus is on the land use system itself rather than other external influencing systems such as economic systems and demographic systems. Moreover, data collection should not be too difficult and time-consuming for achieving the overall target of this research.

Based on the comparisons and the research focuses, we have chosen CA as appropriate for our research. And the boundaries for CA is set as follows: existing land use patterns influence future land use in three ways: the inertia of land uses in a location which reflects the land uses persist over time is one thing; the ease of land use conversions which represents the hierarchy of land use attractions for users is another and the last is the attraction or repulsion effects from surrounding land uses whose influence decreases with increasing distance till zero according to Tobler's first law of geography (Tobler, 1970; van Vliet et al., 2013). Detailed literature review for Cellular Automata is presented in the following paragraphs.

CA is a bottom-up approach to model complex systems dynamically. Space is represented as a grid of cells. Each cell is influenced by its neighbors (Lai & Dragićević, 2011). These spatial dependencies, normally called "neighborhood rules", are crucial for CA models since they are the keys to modeling cell interactions. These local rules can generate complex patterns at global scales so that the whole is more than the sum of its parts. Researchers have summarised eight basic types of neighbourhood rules which describe the interaction between a pair of land uses (van Vliet et al., 2013). In these eight types, different land uses have various influences on other land uses based on neighbourhood distances. In the centre of CA modelling, neighbourhood rules are of great importance since they define the local interactions for modelling global behaviour (Shi & Pang, 2000). And the most common way to calibrate a land use change simulation model and to check the rule settings is to compare the simulated land use maps with the actual maps from the same year. Several statistics are developed to calibrate the constructed land use change model such as Kappa (Monserud & Leemans, 1992), Kappa simulation (van Vliet, Bregt, & Hagen-Zanker, 2011), and Fuzzy Kappa simulation (Hagen-Zanker, 2003; van Vliet et al., 2013). Kappa is a commonly used statistical measure the agreement of two categorical maps, corrected by the expected agreement. Kappa simulation references to the initial land use map by comparing the amount of each land use change. Values above 0 indicate predictive power. 1 represents the perfect fit. Fuzzy Kappa Simulation combines both the original map and geographical fuzziness for distinguishing between small and large disagreement in position and land use types in the comparison.

Despite CA's significant contributions to land use change modelling, more detailed limitations have also been widely criticised. Firstly, there is no generic way to set these rules systematically for each study area. Neighbourhood rules are often defined by trial and error (Hagoort, Geertman, & Ottens, 2008). This process is normally performed by experts on land use modelling (Karimi et al., 2012). The experts look and compare the historical land use maps to set initial neighbourhood rules. After comparing the simulated results with actual maps, they adjust the initial neighbourhood rules, and this is a long and iterative process. Only experts with much experience can do this job. This trial and error process requires much time and is still difficult for the experts to explain why they come up with precisely these neighbourhood rules instead of other rules. Secondly, it is difficult to calibrate the model (de Almeida et al., 2003; Engelen & White, 2008; Kamusoko & Gamba, 2015; Verburg et al., 2004; Wu, 2002). Thirdly, in CA modelling, space is presented by regular homogeneous cells. Raster-based CA has been used extensively for simulating land use changes because of the simplicity of computations and their conformity with pixel-based data (Abolhasani et al., 2016). However, simulating through irregular CA can better represent the actual land use change process since the urban unit is organised based on parcels in reality (Barreira-González, Gómez-Delgado, & Aguilera-Benavente, 2015; Lu, Cao, & Zhang, 2015). Using raster-based data costs information and precision loss since many grids contain not only just one land use type. Specific land use types such as industrial sites are relatively large and irregular which require more precise space structure to be represented. Fourthly, the recent land use redevelopment trend requires more attention to model the impacts after transitions (Banzhaf et al., 2017). To overcome these shortcomings of traditional CA models, attempts have been made. A thorough review of applications is presented by van Vliet *et al*. (2016). Artificial intelligence techniques such as neural networks, decision trees, support vector machines and random forests are used to generate the neighborhood rules automatically (Basse, Charif, & Bódis, 2016; Kamusoko & Gamba, 2015; Li & Yeh, 2001, 2002; Liu et al., 2008; Liu, Feng, & Pontius, 2014; Pijanowski et al., 2005; Yang, Li, & Shi, 2008). Another way to overcome the difficulty of generating neighbourhood rules is to use statistical analysis approaches such as regression models and Bayesian networks (Celio, Koellner, & Grêt-Regamey, 2014; Ku, 2016; Liao et al., 2016; Verstegen et al., 2014). The fuzzy set theory is also applied to urban growth CA models (Al-Ahmadi et al., 2009). To analyse neighbourhood characteristics of land use patterns more transparently, Verburg *et al*. (2004) have studied the enrichment of the neighbourhood by specific land use types for every location in a rectangular grid. Efforts have been made to incorporate vector shapes into CA models, but further calibration and validation are still underway ((Barreira-González, Gómez-Delgado, & Aguilera-Benavente, 2015). Several platforms and decision support systems have been developed to perform land use change simulation. This includes CLUE (Verburg & Overmars, 2009), Land Use Scanner (Koomen, Hilferink, & Beurden, 2011), UrbanSim (Waddell, 2002), SLEUTH (Clarke, Hoppen, & Gaydos, 1997) and METRONAMICA (van Delden et al., 2005).

Even though these efforts try to solve the CA limitations, there are still four types of gaps. Firstly, it can be observed that, the complexity and the limited interpretability of such automatic rule generation models make it hard to implement these techniques and explain to the users. Overfitting is also common in this type of approaches. Land use change modelling not only requires acceptable correctness of simulated results. More importantly, it seeks for a better understanding of the underlying mechanism of land use change and an easier communication process to the users. Secondly, urban space transformations do not follow the pattern of a regular raster structure but fit into the pre-existing land structure with irregular parcels, such as industrial site transitions. Prominent irregular shape features' impacts might be lost if they are rasterised first for land use change analysis. Thirdly, even though many platforms or software packages are developed for land use simulation, they require specific data formats which need extensive data processing time in advance (Hansen, 2007; Koomen, Hilferink, & Beurden, 2011; van Delden et al., 2005). Fourthly, past land use development trends also influence the future land use scenarios of each region. This process is path-dependent and context specific.

To deal with these issues, firstly, simple ways without much data effort for detecting industrial site redevelopment and analysing the impacts of such redevelopment on the surroundings are going to be addressed in this research. Secondly, irregular parcel shapes are going to be applied to maintain information quality. Thirdly, manipulate data in an time-efficient way is going to be explored. Fourthly, path dependency and regional contexts are going to be addressed (Petrov, Lavalle, & Kasanko, 2009; Pettit, 2005).

2.5 Holistic sustainability evaluation frameworks[6]

Sustainable development has become a critical issue for land use planning and management since the 1980s. Various sustainability assessment systems have been used to evaluate and promote sustainability on different scales. Many sustainability assessment methods are reviewed by this research, including OECD core set of indicators for environmental performance (OECD, 1993), IUCN resource kit (Guijt, Moiseev, & Prescott-Allen, 2001), Dutch quality of life indicators (Marans & Stimson, 2011), Dutch sustainable development and green growth statistics (CBS, 2013), and other sustainability assessment systems, for selecting suitable indicators based on our goal setting and industrial land use reclassification references.

Some examples are listed here to give an overview of the current practices. A methodology is proposed based on the analytic network process and Delphi-type judgment procedure to strategically evaluate sustainable tourism for National Parks in Venezuela (García-Melón, Gómez-Navarro, & Acuña-Dutra, 2012). For sustainable agricultural systems assessment, SEAMLESS (van Ittersum et al., 2008) and SAFE (van Cauwenbergh et al., 2007) frameworks are developed. An inventory approach is proposed for rural land sustainability indicator selection (Walter & Stützel, 2009a, 2009b). For urban residential development, system dynamics, GIS, and 3D visualization are combined for the sustainability assessment, proposed by Xu and Coors (2012), while Glass, Scott, & Price. (2013) instead pay more attention to the process for developing such assessment toolkit for upland estate management in Scotland. Besides sustainability study in different domains, a tremendous amount of literature exists regarding sustainability evaluation for various spatial levels. The best-known building level assessment tools are BREEAM (BRE, 2006) in the UK and LEED (United States Green Building Council, 2007) in the USA. Moles *et al.* (2008) present a methodology for sustainability measurement at settlement level based on 79 Irish settlements. Wiek and Binder (2005) develop a decision support tool to assess sustainability on the city-regional level. For urban level, a framework model for assessing sustainability impacts is presented by combining a set of generic sustainable development indicators with workshop validation by stakeholders (Xing et al., 2009). Another paper uses a sensitivity model approach to analyze urban development in Taiwan based on sustainability indicators and expert participation (Huang et

[6] Modified based on: Wang, T., Han, Q. & Vries, de, B. (2014). A model for constructing sustainability assessment framework - focus on regional industrial land redevelopment. Proceedings of ISSRM 2014- 20th International Symposium on Society and Resource Management. June 8-13, 2014, Hannover, Germany.

al., 2009). Principal Component Analysis is also used for urban land use sustainability assessment indicators selection process (Zhang, Wu, & Shen, 2011). Besides a specific case study area, a comparison study between various practices for urban sustainability indicator practices is presented to reveal how different indicators are selected but also suggests the need for consistent processes for choosing indicators based on benchmarks obtained from best practices (Shen et al., 2011). On a regional level, sustainable land resource assessment models exist (Dilly & Hüttl, 2009; Dilly & Pannell, 2009; Li et al., 2001; van Zeijl-Rozema, Ferraguto, & Caratti, 2011). A pan-European level study exists as well such as the aggregated framework to link indicators associated with multi-functional land use planning options to help stakeholders in the evaluation process (Paracchini et al., 2011).

Specifically for industrial site redevelopment, it has been noticed that the European Union and its member states provide different public incentives to make brownfield regeneration more attractive but rarely consider their sustainability (Thornton et al., 2007). Attempts have been made before such as the RESCUE project (Bleicher & Gross, 2010) and the SAFINA project (Morio, Schädler, & Finkel, 2013; Schädler et al., 2011; Schädler et al., 2013; Schädler et al., 2012; Thornton et al., 2007). These projects provide tools for purposes like sustainability evaluation, redevelopment option selection, and cost-benefit analysis. It can be observed that their aims are either too generalized or too context-specific. As is the case for other research on sustainability assessment indexes (Cornelissen, et al., 2001; Dilly & Hüttl, 2009; Fraser et al., 2006; Gasparatos, El-Haram, & Horner, 2008; Graymore et al., 2008; João, 2007; Linster, 2003). To include a sustainability assessment for industrial site redevelopment practice, Schädler *et al*. (2013) have proposed an automated assessment framework for land use sustainability evaluation. In this study, a German industrial site is used to illustrate the scheme for the evaluation of sustainability indicators which have been selected by stakeholders from earlier studies (Müller & Rohr-Zänker, 2009). Even though this research focuses not especially on automatic sustainability evaluation process for different land use options for industrial site redevelopment, this study gives a starting point in selecting possible indicators for brownfield redevelopment, based on European situations. Furthermore, the authors also present indicators impact range, whether they are on a regional level or on-site level or both, together with the required input data. For contaminated industrial sites, an assessment method has been developed to support decision making in contaminated site management and select remediation options in Austria using sustainability principles based on cost-effectiveness analysis. Specific focus is paid on contaminated site management by involving relevant stakeholders from

Austria (Döberl, Ortmann, & Frühwirth, 2013). In Finland, a decision support tool is also presented to prioritize risk management options for contaminated sites by adopting multi-criteria decision analysis and sustainability indicators (Sorvari & Seppälä, 2010).

However, from the literature review, it can be concluded that regional specific sustainability evaluation framework is needed for industrial site redevelopment evaluation. This framework needs to combine the previous study results with regional expert opinions from one specific region and the assessment should be on both site and regional level. Furthermore, the evaluation should be from not only social, economic and environmental point of view, but also from physical point of view.

In this research, regional specific industrial site redevelopment practice is going to be addressed when designing the sustainability evaluation framework, with a special focus on physical aspects additional to social, economic and environmental aspects. Site and regional level combinations are going to be explored.

2.6 Literature review conclusions and SIRPSS requirements summary

This section firstly briefly concludes the literature review and then lists the specific requirements to be fulfilled for the new SIRPSS.

2.6.1 Literature review brief conclusions

This chapter explains the current start-of-the-art of planning support system (PSS), multilevel data integration with a focus on BIM and GIS data, case-based reasoning (CBR), and industrial land use transition analysis and modelling, and holistic sustainability evaluation within the scope of industrial site redevelopment practice. Several conclusions are made regarding the current gaps in research which are going to be fulfilled in this research.

For PSS, they are either on theorectial level for deicison making or are mainly used for site selection or redevelopment proposal assessment instead of for the whole life cycle analysis of industrial site redevelopment. Furthermore, industrial site redevelopment impacts on the whole region needs to be emphasized.

As mentioned in section 1.2.3, geospatial environment data and detailed building information should be combined in the system to find a suitable facility to reuse from an abandoned industrial site. But since the formats from these two data sources are completely different, it is difficult to integrate them.

The application of CBR in the urban planning field is limited, especially when talking about combining top-down governmental supply of industrial sites with bottom-up specific requirements based on private developers.

When constructing the calibrated CA land use change simulation model for industrial site redeveloplent impact analysis and prediction, irregular vector shape of industrial sites, time-consuming data collection, raster map information loss, and path-dependency for industrial site transition and regional context-specific issues need to be tackled.

Regional specific sustainability evaluation framework is needed for industrial site redevelopment evaluation which should be on both site and regional level. Furthermore, the evaluation should be from not only social, economic and environmental point of view, but also from physical point of view. Scenario analysis based on future land use simulation results are not performed in the sustainability assessment process.

2.6.2 Summarized SIRPSS requirements

For industrial site redevelopment, clear guidance is missing on how policymakers can sustainably redevelop an industrial site with the help of e-planning tools. Interactive spatial tools are specifically promoted and favoured by planners according to a Dutch case study for regional adaptation design, regarding energy consumption planning (Eikelboom & Janssen, 2013). As argued by Pert, Lieske and Hill (2013), interaction should be promoted among stakeholders through two aspects: the ability to alter variable weights to reflect different requirements and visual dynamic updated attribute values. In the same sense, public participatory GIS or PSS is in favour by planners for the transparency of decision-making process and convenience of communication, as presented by Brown and Kyttä (2014) and Wang *et al.* (2008). Moreover, real-time visualisation of urban sustainability indicator values can help improve the decision-making process, as claimed by Isaacs *et al.* (2013). Therefore, in this research, computer-aided tools are going to be developed to facilitate public participatory planning process and make the planning process more transparent.

Data from various sources should be integrated to perform the holistic evaluation, analysis and examine tasks, as argued in Yeo and Yee (2014). In their proposed PSS, building information and GIS data are integrated into the designed database for energy use for environmentally friendly urban planning. Furthermore, GIS and BIM integration should help to manage the whole life cycle of redevelopment practices and building information is necessary for facility reuse and suitable site selection. So, to integrate data from both GIS and BIM, we are going to use the IFC geospatial location attributes. As defined by the IFC standard, a site may include a definition of the single geographic reference point, specified by its latitude, longitude, and elevation. This is a key factor that we are going to explore which helps us to link a building model to a feature in a GIS database. This method is different from others found in literature for example by building an integrated system or by converting one format into the other.

To learn from the past for industrial site redevelopment, it is necessary to store experience in computers to help to reason for a suitable redevelopment strategy. Furthermore, it is important to combine the demand and supply sides to stimulate industrial site redevelopment for a region. In other words, public parties' supply of industrial sites should be connected to individual's demand for industrial sites. As a result, CBR methodology is going to be applied to help define case structure and to combine the identified two land use development models so that industrial site redevelopment process can be promoted by combining both public and private parties' preferences. Regarding the usage of CBR to facilitate industrial site redevelopment, three requirements are going to be fulfilled regarding case representation structure. Firstly, urban planning tasks require dynamic update based on new situations so that sustainable goals can be achieved and the possible failures and unnecessary costs can be avoided in the beginning. Therefore, attribute values before and after the transition need to be recorded in the case structure. Secondly, different spatial or professional contexts have different planning preferences. These decision preferences for each region, which are called visions here, should be included in the case representation structure so that focuses on each case are encoded in the case library. These regional development visions from the government should be coupled with the specific requirement from private parties to find the most suitable redevelopment sites and to design the most suitable redevelopment strategies. Thirdly, only cases that have similar demographic and spatial characteristics should be considered as possible references for a new planning case (Du et al., 2010; Li & Liu, 2006). In this research, a hierarchical representation structure is going to be developed which not only groups cases into different categories based on redevelopment visions but also for cases in each category, attribute values from various aspects should be recorded, which changes before and after the transition. Some other requirements regarding the use of CBR are listed as well. To find the most important attributes for industrial site redevelopment for a specific region, interviews, and questionnaire should be designed to consult experts from a region. Another approach could be using a machine learning approach to find the most important attributes for each industrial site transition form in a region. Big data could be collected, and classification algorithms could be applied to test which attributes can produce the most accurate industrial site transition forms. Constructing such a case library requires considerable amounts of data. Detailed planning documents are needed to understand the planning process better. Zoning plan documents are vital sources for such knowledge extraction. However, it can be troublesome to link zoning plan documents to redeveloped industrial sites. Analyzing these detailed documents manually is tedious and time-consuming. Spatial data manipulation and data mining tools should be developed to provide researchers with possible solutions, such as using text mining techniques to analyse descriptive and detailed zoning plan documents (Feldman & Sanger, 2007, pp. 4–10). Biswas, Sinha and Purkayastha (2014) have also stated that integrating CBR with machine learning or data mining techniques would significantly improve the performance of CBR systems. Possibilities include coupling with decision trees to find the most significant attributes to describe a case.

Dynamic evaluation of land use situation is necessary for physical impact analysis and can link the redevelopment result into the future regional sustainability evaluation. After a thorough review, CA is a suitable modelling approach for our study. There are six requirements for a CA land use change model to be useful for decision support of our problem. Firstly, the CA model needs to be realistic in the sense that the predicted land use situation should resemble the actual situation to a certain extent (Karimi et al., 2017). Resemble the actual situation does not mean 100% replication, but the simulated results should be representative of what has happened. To what extent the model is representative enough is typically determined by the users. Secondly, to explain the model to end-users, modellers should document how land use changes are modelled and what kind of rules have been applied (Sugumaran & de Groote, 2011, p. 445). As Hagoort, Geertman and Ottens (2008) claimed, the neighbourhood rules need a better empirical foundation before they can be applied to support spatial policy. Thirdly, to deduce the land use change rules and compare historical data with actual data, Hansen (2012) argues, detailed data from at least three years are needed to compare land use compositional changes, and they need to be collected from the same reliable source and manipulated in the same way and the effort in acquiring and longtime of manipulating data for decision support should be considered in the design of the land use change models. Fourthly, industrial sites are parcel based and typically not in regular shapes. As a result, industrial sites redevelopment requires precise information of feature shapes, especially for the features with irregular shapes (Lu, Cao, & Zhang, 2015; Moreno, Wang, & Marceau, 2009). To analyse industrial site redevelopment process, the shapes of industrial sites need to be emphasised. Fifthly, it is essential to understand the reason and the impacts for each specific region where industrial site redevelopment is located. In other words, this is context specific. Lastly, to make the land use modelling process less time-consuming, computers should be used to analyze regional land use change patterns and automatically generate neighbourhood rules for land use simulation. In this research, computer-based tools are going to be developed to provide generic analysis possibilities for each region (Wang, Shen, & Tang, 2015) and make the data manipulation less time-consuming and adaptable to other regions. A systematic and generic way to analyse industrial land redevelopment process and understand its impacts on neighbouring land uses after the transitions for each region is going to be developed. As a result, regional specific land use change models can be constructed.

Stagnating industrial land redevelopment process requires pro-active and cautious planning to mitigate pressures on the environment and competitions for the precious land resource. A sustainability assessment system is going to be developed which is project dependent and multi-scale structured (João, 2007). In the meanwhile, the assessment framework should be multi-disciplinary, temporal and spatial dynamic with stakeholders' involvement (Singh et al., 2009). To fulfill these requirements, a thorough analysis of this region is essential to define sustainaiblity indicators (Graymore et al., 2008). A goal should be defined together with stakeholders. After examining different frameworks, suitable indicators should be extracted together with stakeholders. This is a repetitive process to eliminate bias from different disciplines. A set of indicators should come from different disciplines namely society, environment, economy and physical surroundings (Gasparatos, El-Haram, & Horner, 2008; Hacking & Guthrie, 2008; Sharifi & Murayama, 2013). Analytic hierarchy process should be applied with stakeholders to determine the weights of different indicators on the same level (Tudes & Yigiter, 2010; Wang et al., 2013; Wedding & Crawford-Brown, 2007). To calculate individual indicators, both short and long-term effects should be taken into consideration, together with spatial effects. That means the evaluation should be dynamic and tempo-spatial oriented. As a result, sustainability evaluation should be connected with land use change simulation models (Deal & Schunk, 2004; Hewitt & Escobar, 2011b; Naddeo et al., 2013; Xu & Coors, 2012). A matrix should be made of the selected indicators in this research. The matrix should be constructed together with stakeholders based on two principles. One principle is to include social, economic, environmental and physical aspects in the assessment, while the other is to include both site and region level indicators. The selected indicators are allocated in the matrix based on these principles, and with a concern of tempo-spatial oriented criteria.

CHAPTER 3 SIRPSS

A PSS called Sustainable Industrial Site Redevelopment Planning Support System (SIRPSS) is proposed. Chapter 3 presents the proposed planning support system (PSS) and the incorporated functions, including multilevel data integration, land use change simulation, sustainability evaluation, site suitability calculation, similar case retrival and visualization. Section 3.1 introduces the schema, followed by detailed research flow. The data integration section is provided to show how building-level information and geospatial attributes are combined within the proposed framework. More detailed information for each of the system functions can be found from section 3.3 to 3.6. The terminology part at the beginning of this dissertation gives a clear explanation of these terms.

3.1 Theoretical framework

3.1.1 SIRPSS schema

Figure 3.1.1 presents the schema of SIRPSS, composed of four modules, which is a general description of the system.

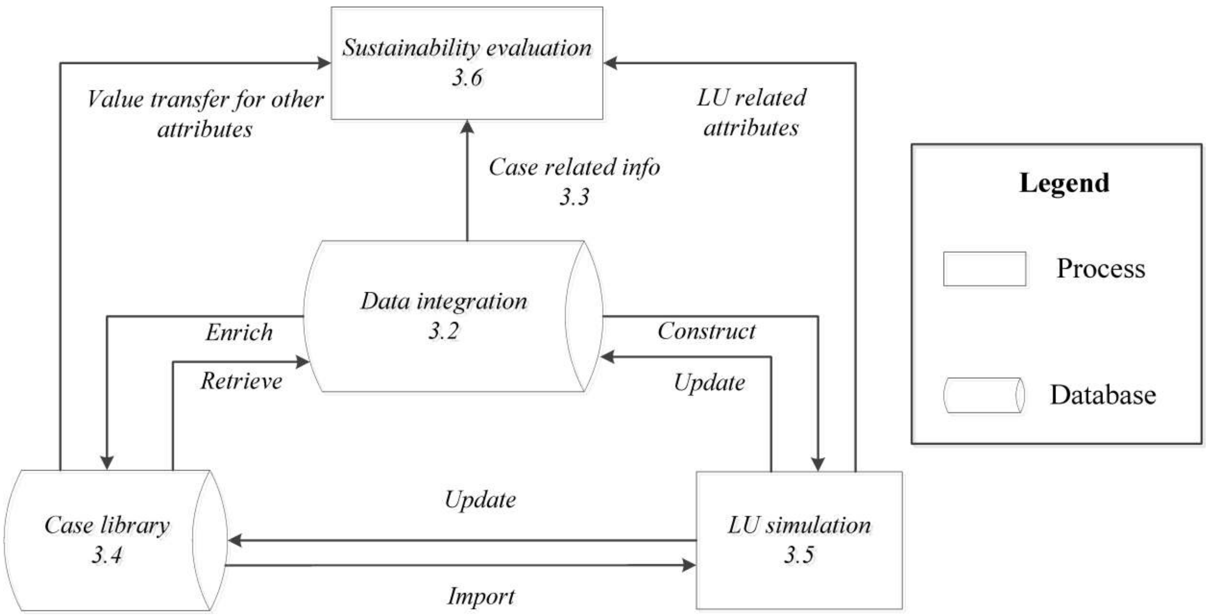


Figure 3.1.1. SIRPSS schema

GIS, BIM and other data are integrated into the GIS environment as a *data integration* module so that suitable redevelopment site can be found based on user requirements. Furthermore, the data integration module is also used for *constructing a land use simulation module* based on historical land use data. A *case library* is constructed which contains redeveloped case information for the same region. The case library includes not only GIS, BIM and other quantifiable information for each case, but also zoning documents. Two zoning plan document examples can be found in Appendix D. Zoning plans follow similar structures which contain project introduction, legal concern, environmental concern, financial aspects, and process organization. The case library is *enriched* by the data integration module. Based on the selected suitable site for redevelopment from the integrated data module, the case library is consulted to *retrieve* similar cases from the case library. The case library helps to design target site scenario, and these designed scenarios are *imported* into *land use simulation module* to update GIS data in the data integration module. The selected redevelop site information, *land use related attribute* and *other attributes* which can be obtained from the *case library* are used to evaluate *sustainability*. After the design and implementation of each new case, the new case is included in the case library, which is named as *Enrich*.

3.1.2 Research flow

To explain the whole process better, in this section a research flow chart is presented. Based on future *users' requirements* for a site and the regional *visions from planners*, suitable sites for redevelopment can be found based on the suitability calculation in GIS environment which integrates *land use, building info,* and *other data*. According to the same principles, regional visions for redevelopment and user requirements can also be used to find the *similar cases* from the case library constructed. Not only *planner visions* for a region's redevelopment direction should be used to find similar past cases, but also other attribute values such as each site's accessibility to infrastructure, environmental zones, surrounding situations, population density and so on should be considered. The *planner visions* support us to find the similar cases for the first step, and the *user requirement* values support us finding the most suitable cases. The *redeveloped case zoning documents* for similar redeveloped cases can be used to compare the past experience with the current site at hand. Their similarities and differences can be identified to help design the most suitable strategy for the new sites. Following the *chosen suitable strategy*, the new *site can be designed*. The new design will be digitalized as a zoning map. The *zoning plan importation* is performed to incorporate this new design into *land use simulation* model so that future land use situation can be presented. The past experience from zoning documents and the new simulated land use situation for the newly designed industrial site can be used to evaluate possible outcomes of the newly redeveloped site, both for *site level indicator evaluation* and for *regional indicator evaluation*.

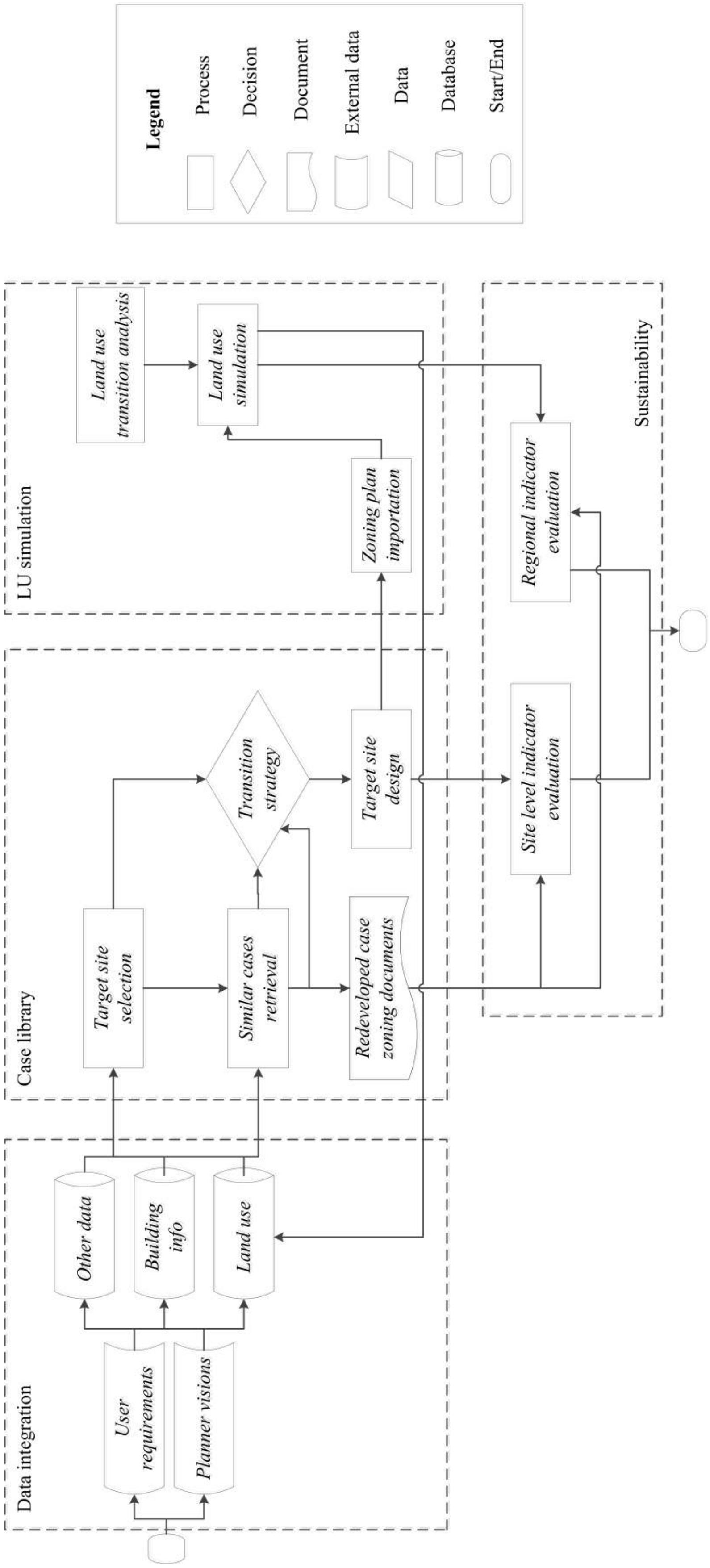


Figure 3.1.3. Research flow

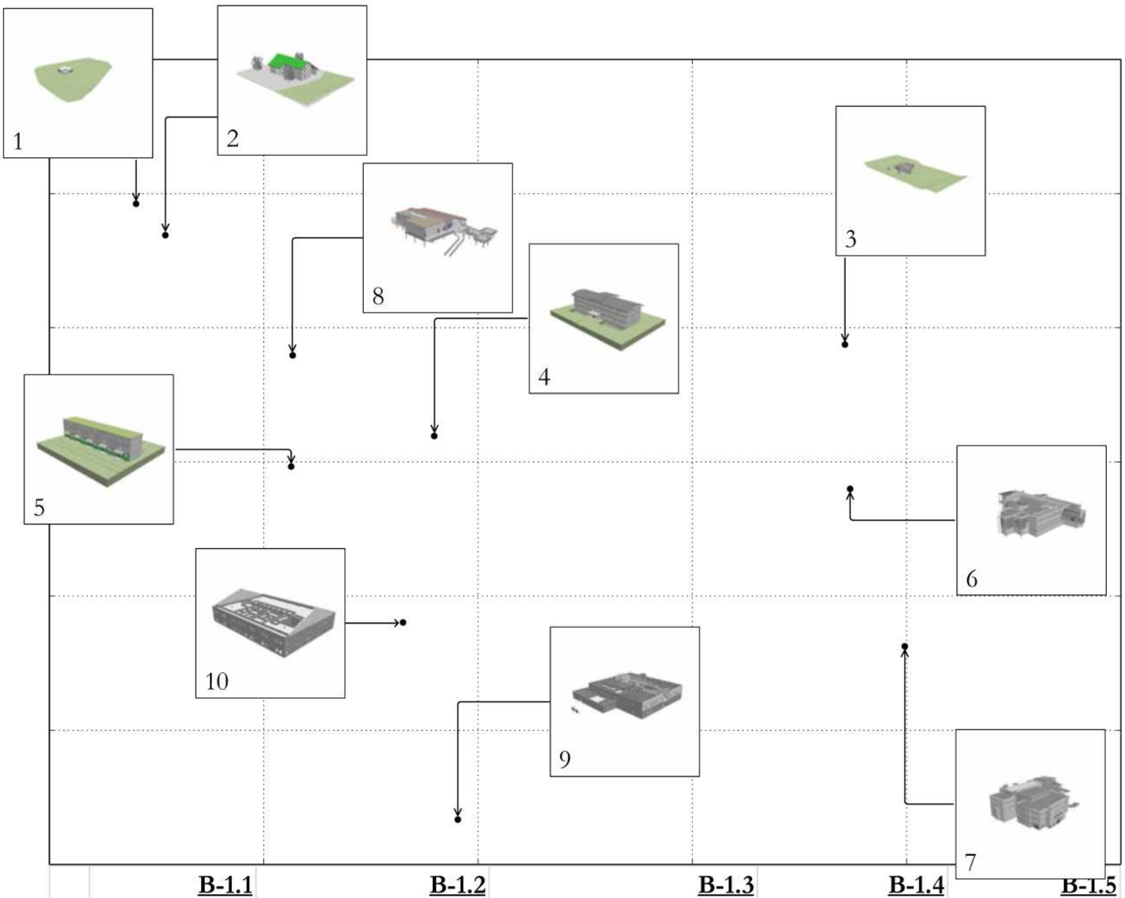
3.2 Data integration

As mentioned in the introduction part, redeveloping an industrial site also needs to consider the buildings on the site; as a result, building information is combined with GIS environment attributes and this integration of two data sources is explained here. For better evaluating the current status of industrial sites, extra information from building level (*building info*) is necessary, such as the floor area, vacant rate, primary activities, and energy consumption. More information for buildings can be added later according to the users' preferences and decision criteria. Section 2.2 provides a literature review of both BIM and GIS data formats and the difficulties in integrating these two sources. This serves as a starting point. In the data integration module, particular focus is put on combining building information with other data in GIS instead of integrating them, the detailed rationale is explained in section 3.2.1; a framework is presented where loosely coupled building data can be added into the geographic environment. As a result, data formatting issues can be avoided.

3.2.1 The proposed approach to combine BIM and GIS data

Because of the difficulties in translating between IFC models and geospatial dataset which causes information loss, a loose coupling approach is proposed to combine BIM and GIS data. The proposed approach is based on a combined feature extraction method and therefore does not rely on a shared common denominator between the BIM and GIS input formats. The idea is to extract building attribute values from BIM models and add these attributes into the geospatial dataset, not the other way around to omit translating error and information loss. Since the attributes that we need are pre-defined together with users, they can be later easily queried and added with guidance. For example, as identified in the literature review and shown in Appendix A, several attributes for sure can be extracted from BIM models such as architecture openness, floor area size, ceiling height, to name a few. The reason to extract attribute values from BIM models and add these attributes into the geospatial dataset merely is that there are more data available for GIS implementation. And currently, the government is still the main leading party to industrial site redevelopment. They often look at geospatial environment first to decide the supply. If in the coming years, the leading party is changed and private parties have more available BIM models for existing buildings, then the other way can be implemented and tested, which put geospatial environmental data into BIM model profiles and suitable facilities can be identified based on a profiling approach, which is briefly explained in section 3.3.2 (Wang & Krijnen, 2014).

Practically speaking, BIM models can be imported into tools such as IfcOpenShell ("IfcOpenShell," 2018) to extract attribute values. These values can be then imported into the GIS environment. This results in a modular system in which interdependencies between logic for BIM and GIS processing can be eliminated, and both domains can be queried up to their full potential without data loss. An implementation illustration for five extracted attributes from ten BIM models is presented in Figure 3.2.1.



	B-1.1	B-1.2	B-1.3	B-1.4	B-1.5
	Net floor area	Restroom floor area	Architectural openness	Building height	Ceiling height
1	79.596	3.752	4.568	3.920	2.300
2	97.270	3.348	5.140	5.530	2.480
3	4648.428	16.727	42.623	12.000	3.800
4	2266.660	102.080	8.303	12.000	3.000
5	909.811	206.849	8.403	10.740	2.780
6	5100.000	245.442	46.331	11.700	3.700
7	11728.758	105.826	16.730	20.000	4.000
8	477.682	54.844	7.294	9.450	3.200
9	6935.799	910.335	13.581	10.250	4.680
10	3582.008	384.390	8.703	7.925	4.267

Figure 3.2.1 Illustration of extracted BIM attribute values using IfcOpenShell

The loose coupling has urged to come up with guidelines and best practices for modelling seamless inter-linkage between the two input streams in order to reduce manual effort and errors in data curation. The geospatial database is the starting point for implementing. BIM models can incrementally be added into the system. In order to be able to associate the BIM model with the geospatial information, the building model needs to have a geo-referenced point. The distinct domains can be integrated to enable the coupled feature extraction. This association takes place on two levels. Firstly, by means of the georeferenced point, distances to critical geospatial features can be computed, and land use and other relevant geospatial data can be incorporated. However, in order to link to the attributes related to the GIS feature, the BIM geospatial reference point needs to be contained within the polygon of this building in the GIS. Therefore, the link can be established by a point-in-polygon test. If geo-reference is not supplied in the IFC file, interlinking the two is done manually in a graphical user interface. The extracted information from the GIS and BIM domain may need to be manually adjusted upon ingesting the information into the system.

3.2.2 Data sources for the other modules

For *case library* module, existing zoning plan from the constructed *case library* should also be included, especially the approved industrial site redevelopment land use plan. First of all, these zoning plans provide information such as how many years is needed for a redevelopment project, which can be used for *land use simulation module*. Moreover, the information stored in each case can also help to define changing rules in *land use simulation module*. For example, after the completion of a redeveloped industrial park, more residential areas would probably become necessary in the surroundings, thus in the coming years of simulation, it is very desired that more residential blocks would appear. Thirdly, successful industrial site redevelopment cases plan documents would give suggestions on how a similar site can be redeveloped and what would be the impacts of such redevelopment.

Site selection module is used for determining where the most suitable places for industrial redevelopment are. Therefore, it takes several data sources as input. Firstly, it uses data from *data integration module* and data from *demand and supply estimation*. Secondly it uses the *most important attributes of industrial redevelopment area selection* from the case study database or the *users' preference* (based on weights and attribute values). Thirdly, the *chosen redevelopment strategies* by the users is applied to the selected site for redevelopment.

In *land use simulation module*, constrained cellular automata model is applied which makes it easier to mesh the data from the regional level and site level for abstraction and regional planning evaluation. This is going to be explained more in the coming sections.

Based on literature review and expert interview, *most important sustainable indicators* based on two layers are identified, namely industrial site level and regional level and four aspects including environmental, social, economic and physical aspects. Some of the attributes which reflect sustainability indicator values and can be calculated using *available data for these indicators* are examined and included in the *sustainability module*.

3.2.3 Data integration approach conclusions

Section 3.2 presents specific data integration approach for SIRPSS. Different from other urban planning PSSs, this chapter emphasizes the use of BIM data to support facility reuse on an abandoned industrial site to support sustainable redevelopment process, in accordance with the project assumed conditions. To do that, a detailed literature review is performed in Chapter 2 regarding BIM and GIS data formats. Based on the data formats and possible approaches for their integration, a loosely coupled approach is presented to combine BIM and GIS data. This is in one way helps to consider both public and private parties' interests. On the other hand, makes the selection of suitable industrial sites more holistic using information from various levels. For the whole system, other data sources that are needed to facilitate industrial site redevelopment with a focus on facility reuse are also identified in section 3.2.2 so that better planning support can be achieved.

3.3 Site selection

This section firstly explains how we try to integrate different data sources and then proposes a profiling approach to select suitable sites for redevelopment, with reusing facilities in mind.

3.3.1 Combining public-led and user-oriented models

To find the most suitable site for redevelopment in a region by combining both public and private party's interests, public-led approach and user-oriented models are combined. The public-led model looks at all the industrial sites in a region as the possible supply of industrial sites. To find the most suitable one for redevelopment, these sites are compared with each other using the suitability calculation approach. The suitability is based on summed weighted attributes. This model requires data from regional demographics, distance to difference facilities, safety levels and other possible data sources which is applied to each site in the whole region. The most suitable sites for redevelopment can be found based on the suitability scores calculated by CommunityViz (Placeways LLC, 2013), which is software to help efficiently evaluate various design scenarios based on indicator values, in GIS environment. However, the second user-oriented model requires more building information into the suitability analysis to find the most suitable redevelopment sites. This can add more specific requirements from the private developers. For example, adding more specific building-level information from each industrial site, which requires decision makers not only looks at site level attribute values but also building specific detailed attributes. As a result, requirements from the private parties can be better satisfied. To combine these two models so that regional industrial site supply can be better matched to specific site demand from the actual future users, an approach or framework is presented to show the possibility of combining GIS and BIM data in finding suitable sites for redevelopment. To reflect our assumed conditions for this research as facility reuse, this is further explained and reflected in selecting the most suitable sites for redevelopment by giving high weights to attributes related to facility reuse, such as available floor areas. The system compares the distance between desired facilities by the users to the existing unused facilities in a geospatial environment by calculating distances between various attributes including building information and geospatial attributes and then multiplying them with weights that are given by the users of the system.

3.3.2 A profiling approach

The approach suggests existing vacant facilities to potential customers aspiring to acquire industrial facilities. Prospective owners are asked to provide detailed information, preferably a BIM model, about their ideal conception of a building. The system then composes a vector of quantitative measures that describe aspects of the building and its relation to geospatial resources. Examples of these measures include properties like the floor area and ceiling height of the facility, derived from the document or BIM they provide. Furthermore, distance to, for example, public transport hubs and supply chain partners can be derived from GIS. Lastly, the outcomes of simulation or measurement can be included, for example, the indoor lighting levels on working height expressed in lux. Thus, for abandoned or vacant facilities, a profile is extracted by combining data from BIM and GIS. These can be matched to the requirements supplied by the prospective owner. A set of the profiles that resemble the supply vector can be presented to the prospective users. This set consists of the profiles for which the weighted Euclidian distance to the demand profile vector is relatively small, based on predefined thresholds. As such, they represent vacant facilities that closely match the desired facility as sketched by the client. This approach enables a win-win situation in which, on the one hand, the requirements from the potential users are fulfilled and, on the other hand, existing vacant facilities are matched for redevelopment. The profiling approach presented connects supply and demand for a sustainable future. To be more specific, the vacant facilities span an n-dimensional search space, in which n represents the size of the set of identified attributes. Every vacant facility occupies a point in this space, as does the desired facility, presented to the framework by the prospective owner. The vacant facilities that are close to the desired facility are selected and presented to the client as recommendations. The relation between these facilities can be visualized by means of their attribute values. Vital distinguishing attributes can be represented as an axis in an overview to the user. In such a way, the user can initiate an interactive negotiation process in which the set of vacant facilities is explored. The formula used to calculate the distance between the desired facility and the existing facilities is shown below.

$$d = \sqrt{\sum_{i=1}^{n} \omega_i \, f_i(x) \, x^2}$$

Where d is the weighted distance between an existing facility and the desired facility in the n-dimensional search space, n is the size of the set of identified attributes. Each of the identified attributes is assigned with a weight ω_i according to the stakeholder evaluation which can be obtained using a scientific approach such as analytical hierarchy process while using questionnaires to avoid bias or purely as input from the users based on intuitions. x is the normalized difference between the actual facility value and the desired value for each attribute.

Furthermore, $f_i(x)$ is a fuzziness function (Beg & Ashraf, 2009; Chaudhuri & Rosenfeld, 1996; Montes, 2007) that can be used to model asymmetry and vagueness inherent to the attributes. Suppose the client requires a minimum ceiling height of 4m due to regulations and if one were merely using the squared difference (x^2), this would lead to the surprising assumption that a ceiling height of 4.5m is as preferable as 3.5m. This is apparently not the case, as the latter violates the regulations. As a second example, suppose the client suggests a minimal floor area of 40 000sq. m. Surely some tolerance is desirable so that a facility of 39 800sq. m is still matched. Both these aspects, the asymmetry and the imprecision, are modelled by the fuzziness function. Note that this function is tailored to the attribute and varies based on whether the user specifies a minimum or maximum value. In some cases, this function can also only be a constant $f_i(x) = 1$. Figure 3.3.2.1 illustrates a possible fuzziness function for the ceiling height example, where σ is the standard deviation of the existing vacant facility attributes' values. As the normalized difference approaches $-\sigma$ the weighted distance will approach infinity, rendering this facility unsuitable for selection due to the considerable distance, whereas when the requirement is met, the function trends towards zero, diminishing the weighted distance.

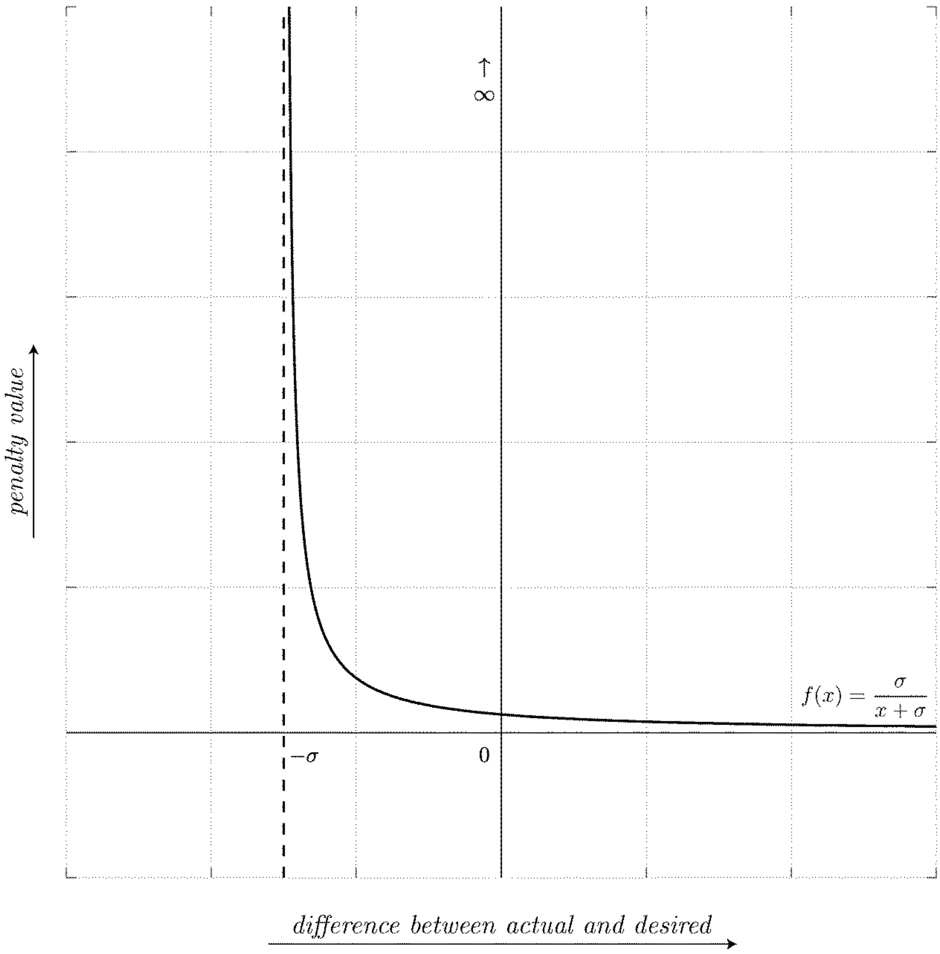


Figure 3.3.2.1. A possible fuzziness function for a minimum value attribute

As discussed in the previous section, some attribute requirements might not be fulfilled entirely by means of the selection process. It is important to realize that the method presented entails an iterative negotiation process between the demand and supply parties. Unmet requirements are not necessarily insurmountable. For example, in the case of the attribute sketched in Figure 2.3.4, it is easy to see that by structural remodelling the two spaces can be made more equivalent, a transformation that comes with a cost. Therefore, the selection process lead by the client can be monetary based, with many of the attribute differences represented as monetary measures. For each of the suitable vacant facilities suggested to the customer, a financial indicator can be composed that reflects the acquisition, renovation and maintenance costs and can also incorporate costs related to geospatial business risks like crime rates and employment conditions. The redevelopment costs can be tailored to a specific client, industry and spatial context. Thus, the prospective owner is able to select amongst the vacant facilities and can compare the associated costs for establishing a newly built facility by means of a unified monetary measure. A graphical depiction of this overview is presented in Figure 3.3.2.2.

3.3.3 Site selection approach summary

Section 3.3 is used to link land use management models in Chapter 1 (see Table 1.2) to the industrial redevelopment site selection procedure. Public and private parties can be better facilitated by considering both of their interests and further industrial site redevelopment process can be promoted.

To combine supply and demand sides, the whole regional industrial site supply is compared with assumed demand parties' interests in facility reuse. As a result, geospatial data which reflect regional supply is combined with building level information which shows also building information on one specific site. To combine these two data sources, a profiling approach is presented.

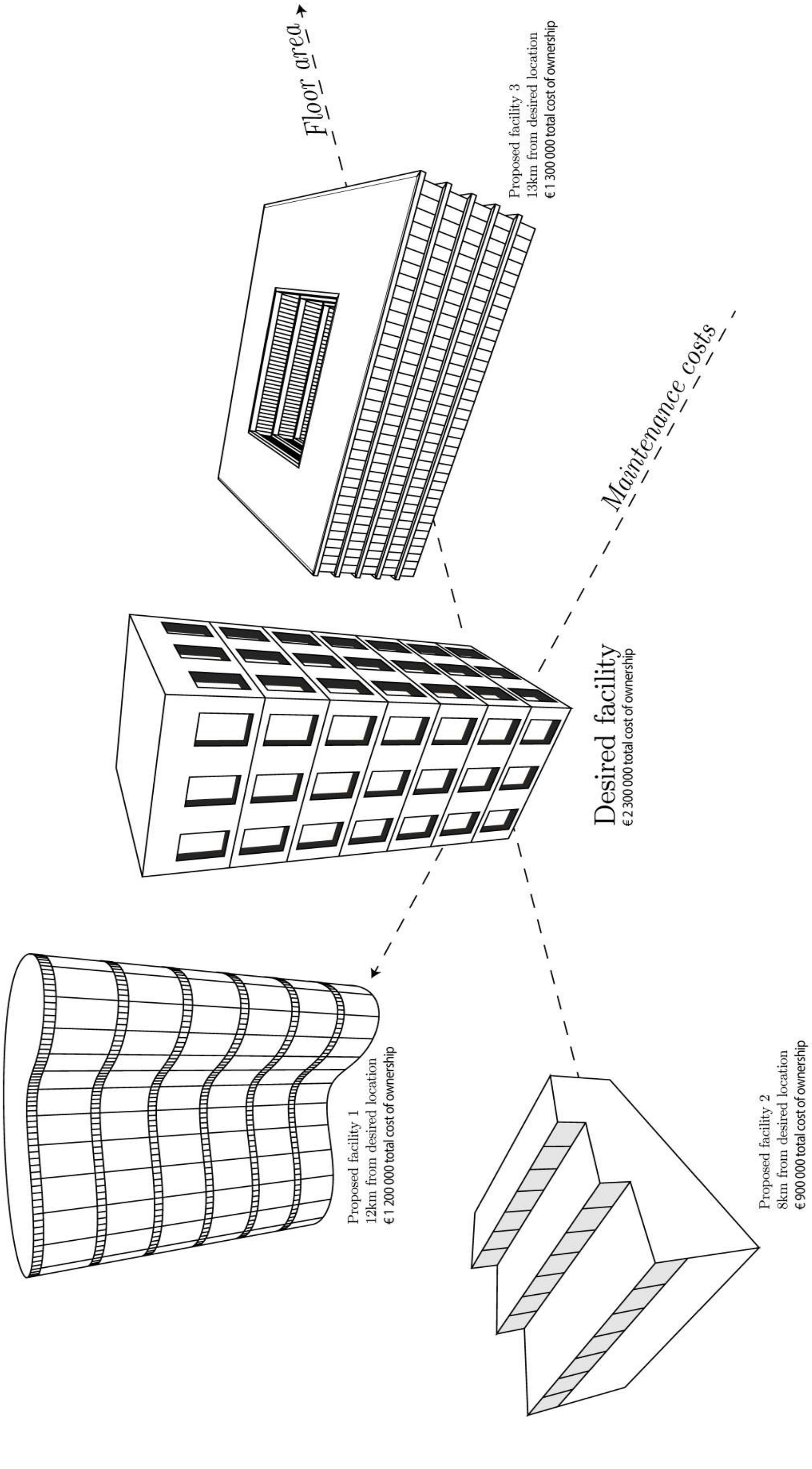


Figure 3.3.2.2. A schematic representation of the facility selection process based on monetary estimation

3.4 Case library

To learn from past experience, CBR is applied in the urban planning field in this research. Computer tools are developed to support regional planners to find similar past experience. These case libraries are based on each specific region at hand. As a result, regional characteristics can be well represented. This section illustrates the proposed use of CBR, the case representation structure, case similarity calculation algorithm, and the developed planning support tool, for industrial site redevelopment.

3.4.1 Proposed CBR solution

In this research, a method is proposed that uses geospatial data manipulation and data mining tools such as *FME*® ("FME Workbench Transformers FME Desktop 2015.1," 2015) and TerMine (Frantzi, Ananiadou, & Mima, 2000) to find information from the associated zoning documents for an industrial redevelopment site. This method provides a general starting point for decision support in industrial site redevelopment. An important benefit of the approach presented here is that solely land use maps and zoning plan maps are needed as input. Rich details can be derived from zoning plan documents which are listed in the zoning plan maps. For analyzing zoning documents, in earlier research, a framework to generate visions from zoning documents is presented (Wang, Han, & de Vries, 2016). A summary of this research is included in the "visions extraction from zoning plan documents" section 3.4.6. Other quantifiable attributes for sustainability evaluation are included in the case representation as well. The most important attributes are identified to reduce the retrieval time of most relevant cases from the case base. With this information included, a redeveloped case can be described in a holistic way. Similar cases can be retrieved not only based on their common visions but also based on quantitative attribute values. Moreover, policymakers can set different weights for each of the attributes that can reflect visions. With different weight settings, different visions can be quantified as well. As an example, for regions that emphasize green living in their main considerations for regional redevelopment, more weight will likely be given to the green area per capita attribute than for regions that give priority to economic development. Additionally, the impact of the redevelopment can be quantified as a result of observing changes in these attribute values after the redevelopment. A temporal change in attribute values provides detailed information on the redevelopment impacts on the site and on the enclosing region.

A case base that is based on the proposed case representation structure is constructed. Complex urban planning tasks require policymakers to discuss and adapt possible solutions, rather than relying solely on an automatically determined solution from similar cases. Therefore, in this research, the focus is put on the retrieval process. A retrieval algorithm is presented to find similar cases from the case base.

3.4.2 CBR implementation process

The CBR flowchart is presented in Figure 3.4.2. The platforms applied are illustrated, together with the tools that have been used or developed.

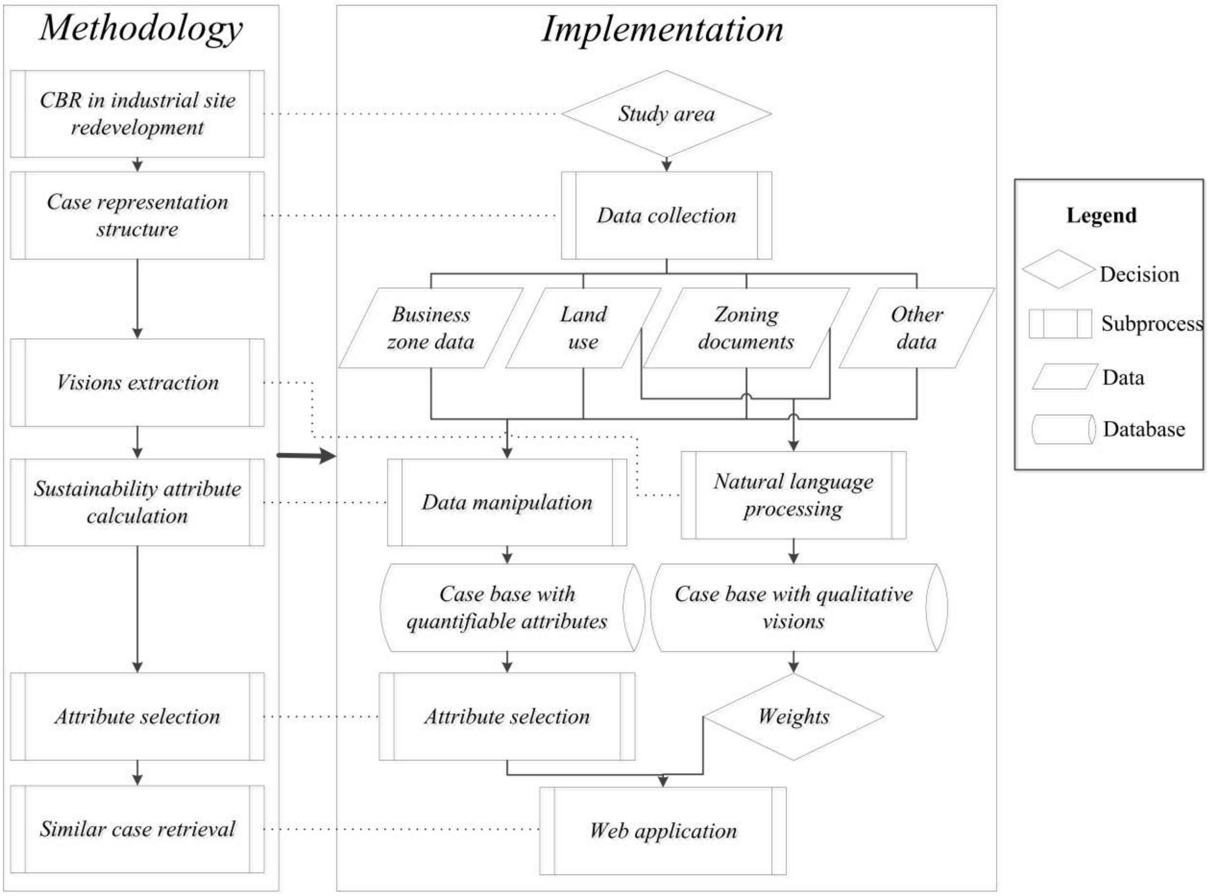


Figure 3.4.2. CBR Research framework and implementation

In Figure 3.4.2., on the left side, the methodology is illustrated. The dashed lines illustrate the connection between theory and practice. Firstly, method has been proposed on how to use *CBR in industrial site redevelopment* tasks. As a result, a suitable *study area* is selected for the practical implementation on the right side. The *case representation structure* requires information about visions and sustainability attributes. This structure determines *data collection* requirements on the right side. Data includes *land use, business zone data* (specifically for industrial site redevelopment problem), *zoning documents* and *other data*. A literature review has been performed to *select attributes* for sustainability evaluation. *Visions* which describe the regional specific characteristics and focuses on redevelopment are extracted from *zoning documents*, using *natural language processing* tools. Other data for the calculation of sustainability attributes are collected to perform *sustainability attribute calculation* to combine with the visions for constructing the case base. The most critical attributes to determine what transition form would be applied to one specific industrial site is identified by machine learning algorithms. This is called *attribute selection* in the framework. As a result, a *case base* is constructed *with qualitative visions* and *quantifiable sustainability attributes*. Based on the user-defined *weights* for these identified features, and the vision for a region, *similar cases retrieval* from the case base becomes possible. A *web application* is developed to illustrate the idea.

3.4.3 CBR in industrial site redevelopment

For the purpose of the industrial site redevelopment, the CBR approach is presented since it can support policymakers to find useful experience from the past and learn from it. This is highly beneficial in relation to sustainable development, as future implications can be assessed as part of the case structure. Figure 3.4.2 presents the research framework and flow, while Figure 3.4.3 illustrates how to embed CBR in the specific field of industrial site redevelopment planning. How to connect regional redevelopment visions to each module of our proposed PSS is presented. Essential aspects are to support policymakers finding similar cases from the case base and analyze them in terms of their transition forms. *Transition forms* here signify the conversion of an industrial site into other land uses.

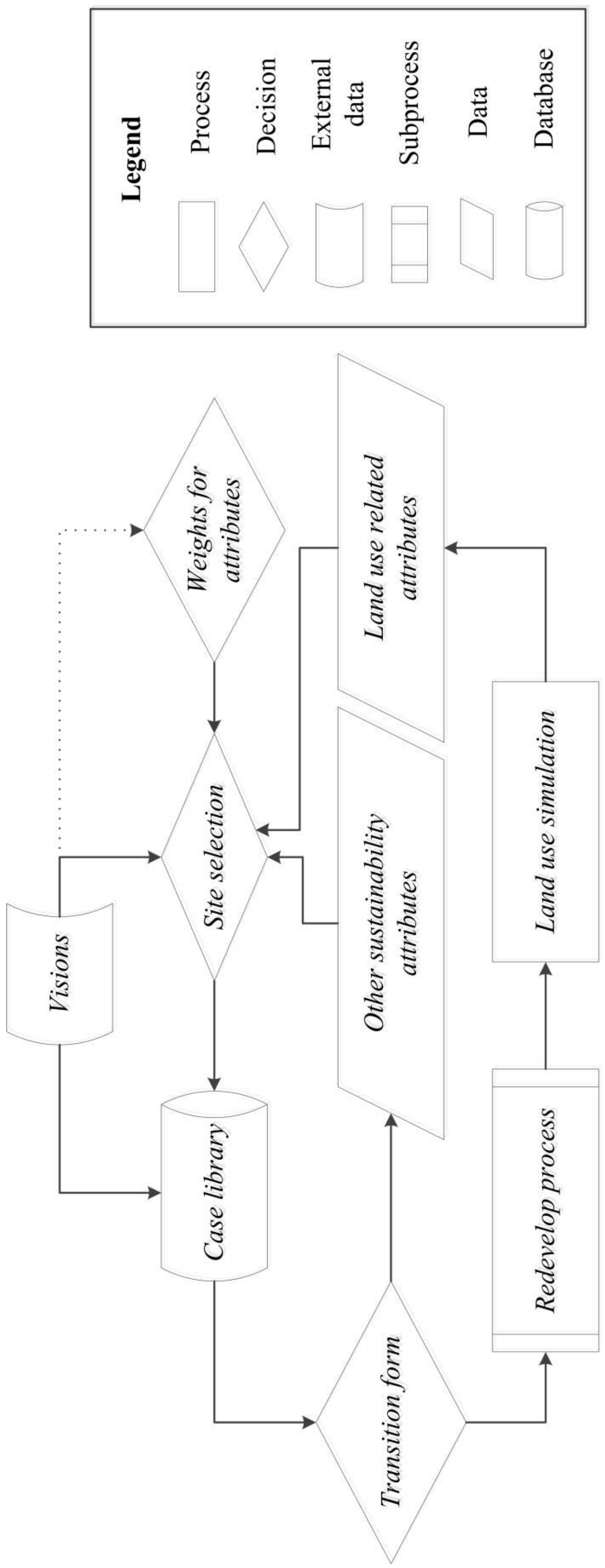


Figure 3.4.3. Proposed CBR approach in industrial site redevelopment planning

Based on the *visions* of one specific region and *other sustainability attributes* values, the most suitable sites for redevelopment can be selected (*site selection*) based on the weighted sum scores of these values. The *weights for attributes* could also be used to reflect the *vision*s. For example, green living vision would require a high weight green space per capita in a region. *Transition forms* of similar cases can influence policymakers to design the transition form for the case at hand accordingly. For example, if most of the similar cases transformed from industry to residential use, it is likely a viable transition for the new case to be transformed into residence as well. A reflection on this among stakeholders will be insightful in analyzing what makes the cases similar and what makes the previous scenarios successful or unsuccessful. In the proposed system, the newly *selected site*, together with its similar cases *redevelop process* can be used as input into the regional *land use simulation*. The simulated results can show insights into the redevelopment process and influences on the surroundings on a larger scale. The impacts on the surroundings include *land use related attributes* like the distance to various facilities. Similar cases' *transition forms* can also give insights on *other sustainability attributes*. The changes in these spatial and other attribute values after the redevelopment can then influence the next round selection of suitable industrial sites for redevelopment. The dynamic procedure can guide several iterations of case selection and transition form design.

3.4.4 Case representation structure

To construct the case base, a case representation structure is essential and proposed to guide the construction procedure, as shown in Figure 3.4.4. Table 3.4.4 later provides a more vivid example of how this structure is applied. The following criteria on how a case could be represented are listed. For each *transition form*, the values for environmental, physical, economic and social *attribute*s are calculated on both *site level* and *regional level*. This ensures that the sites studied are not isolated from their spatial context. For each *transition form*, the values for sustainability attributes are calculated *before redevelopment* as well as *after redevelopment*. Several attributes can help to determine the value of *indicators* on site and regional level. *Indicators* are summarized values calculated based on *attribute* values. The cases need to be constructed based on a hierarchical structure so that different temporal and categorical information can be stored for each *transition form*.

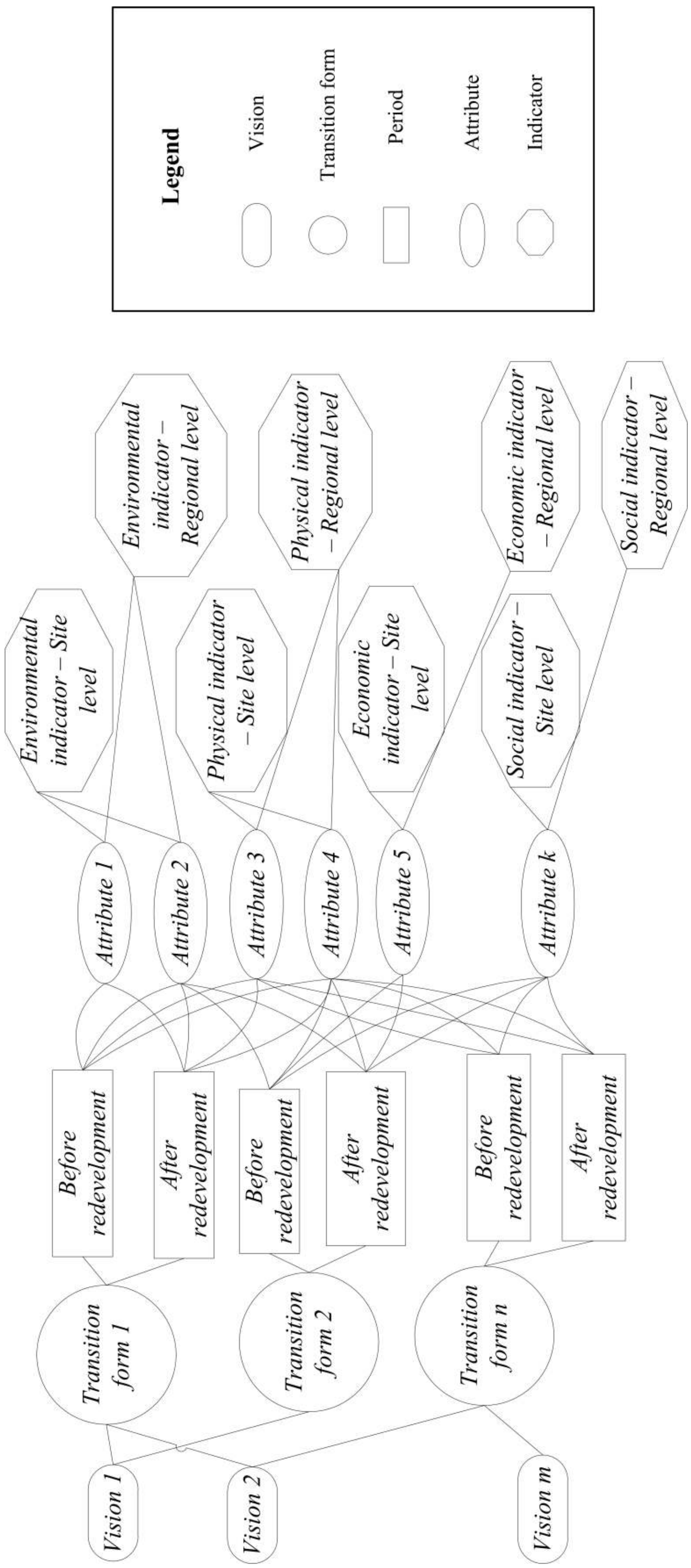


Figure 3.4.4. Case representation structure

To further illustrate the temporal nature of the case representation structure, a partial example is listed in Table 3.4.4. This industrial site has been transformed from *industry* to *retail*. Therefore, the transition form of this industrial site is an industry to retail. Before the transformation, there are 80 *job*s on the site available. After the transformation to retail, 160 *job*s are expected as a result of the *vision* for this redevelopment - "*Economic development*". It is to show that the temporal change of attribute values is included in the case representation to examine redevelopment impacts. *Other attributes* are not listed. Indicators are not listed, but possible indicators can be regional GDP income, which can be derived based on the *attribute* values for *job*s from all industrial sites. Other attributes are not listed here, but more detailed examples can be seen from the case study chapter.

Table 3.4.4. Case representation structure example

Site area	LU before	Visions	LU after	Job before	Job after	Other attributes
1,500 m^2	Industry	Economic development	Retail	80	160	…..

3.4.5 Data collection principles

To extract the visions pertaining to a specific region, planning documents are needed. This helps to analyze the words used frequency so that the most frequently mentioned words (visions) can be identified. This serves as the base dataset for this purpose. And additional data sets are necessary which can help to calculate other relevant attribute values which are listed in the case representation structure such as distance to highway, jobs before the redevelopment and so on. As a result, the following additional data is necessary, such as land use maps, business zone information, transportation networks and the like. They are used in the GIS data processing procedure. Data also needs to provide information for attributes before and after the redevelopment. The change of attribute values before and after redevelopment can give insights into the transition impacts.

3.4.6 Visions extraction from zoning plan documents[7]

Visions guide main directions for a new redevelopment task. Therefore, visions extraction process is emphasized. To extract visions from zoning documents, detailed process is illustrated in the case study in Chapter 4. To find similar cases, the most important visions for each case are used. Figure 3.4.6 illustrates the process to extract regional industrial site redevelopment visions, using zoning plan documents and land use maps.

To give a general idea, land use maps are first analyzed to find changed parcels which are big enough and transit from industry to other uses. These parcels are overlaid with zoning document maps so that the associated zoning documents for these transition sites are identified. Further, the identified zoning documents are analyzed using natural language processing tools so that mostly mentioned visions are extracted from the texts. To be domain specific, the manual selection process is also performed to select the most relevant visions from the automatically extracted vision list.

Land uses (LU) are categorized based on *land use maps* from two years in the first step. In the second step, an *accumulated map* is created which contains land use information for two consecutive years. All the *parcels larger than a threshold size* (10,000 sq m^2) and have been detected *changed from industrial use to other LU* are *overlaid* with *zoning plan maps*. The *specific zoning plans associated with the redevelopment process* can be identified. Therefore, the problem of only a simplified descriptive document exists for a redevelopment case which is typically presented on a website collecting industrial area redevelopment projects is conquered. More information from detailed zoning plan documents can be retrieved for each redevelopment case. Thereafter, a *natural language processing* tool is applied to analyze these zoning plan documents to perform text mining task for finding the most frequently mentioned visions of each redevelopment case. According to the study of all these zoning plans, several *automatic derived visions* that are mostly mentioned such as sustainable development, student housing and so on in a specific context (region) can be identified. This could be used as the basic reasoning rules for designing future similar redevelopment planning tasks. Using the same region redevelopment cases ensures the demographic and political homogeneity. As a result, each case has been described by several frequently used visions from the zoning documents. Domain knowledge and semantics are necessary to provide a context for the usage

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[7] Modified based on Wang, T., Han, Q. & de Vries, B. (2016). Domain knowledge extraction for industrial area redevelopment planning. In H. Timmermans (Ed.), 13th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, 27-28 June 2016, Eindhoven, The Netherlands (pp. 1-14). Eindhoven: Technische Universiteit Eindhoven.

of these words. As a result, *domain dependent manual selection* is performed. These case and visions relationships can be presented using computer tools on a webpage for participatory planning process later.

3.4.7 Sustainability attributes selection and calculation

For a specific region, the most important attributes regarding sustainable industrial site redevelopment should be identified as well so that they can be added in the case base. Based on the literature, a sustainability evaluation framework is constructed. Not only general sustainability evaluation frameworks are examined, but also specific industrial site sustainability evaluation frameworks are studied since a significant amount of obsolete industrial sites is in urgent need for redevelopment in Europe (Morio et al., 2013). From the literature, one can draw the conclusion that for each region, and each specific purpose, an evaluation system with different weight settings and various attributes should be presented after consulting the policymakers from the region. In addition to the commonly used environmental, economic and social aspects, indicators from the physical aspect that provide more information for site selection and surrounding analysis are also listed. This evaluation framework contains indicators that are going to be calculated based on attribute values.

Table 3.4.7 lists the important sustainability indicators according to the literature review process. Some of them are calculated or visualized in the case study chapter using attribute values that can reflect each indicator from these identified categories.

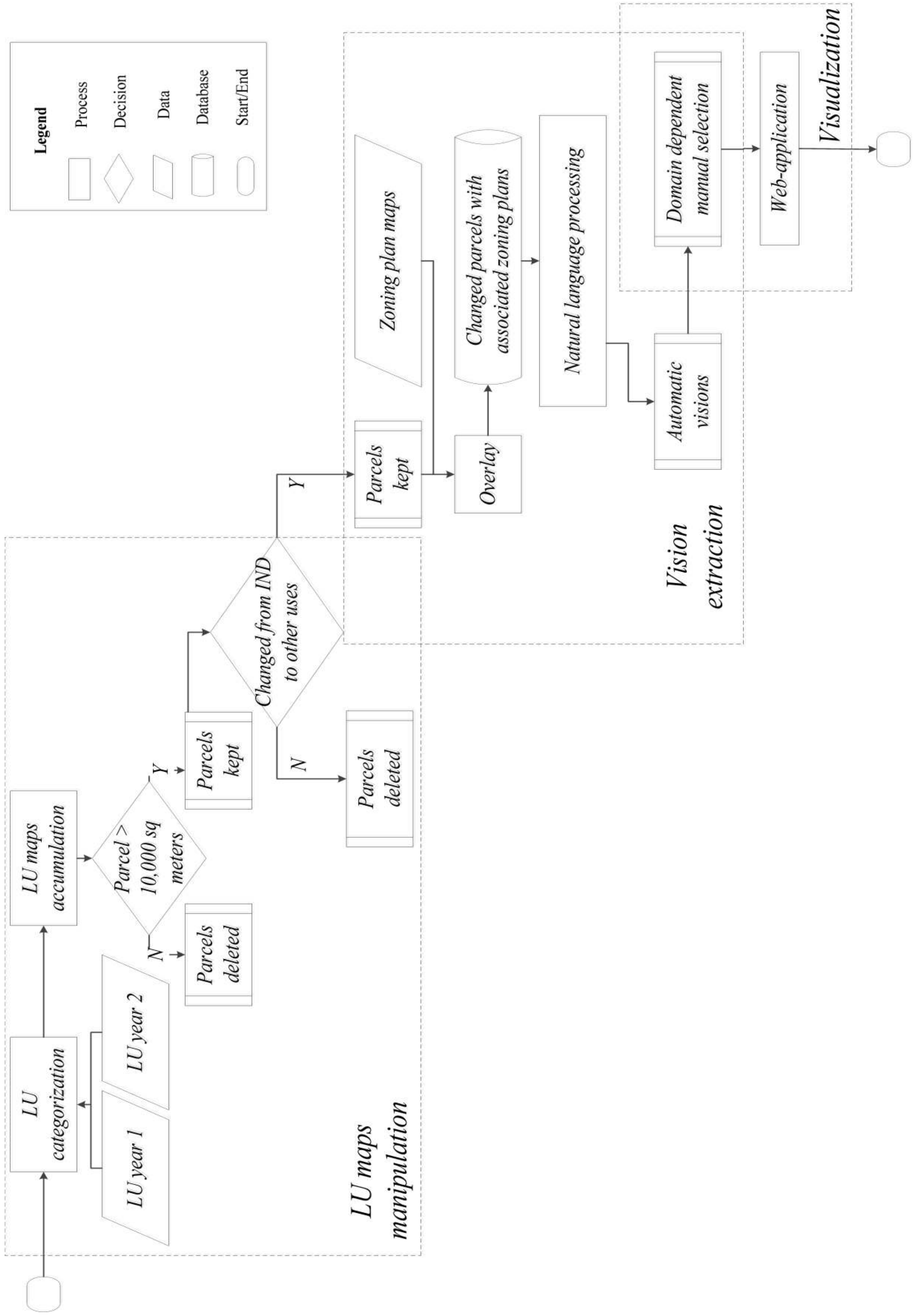

Figure 3.4.6. Case vision extraction process

Table 3.4.7. Sustainability indicators for industrial site redevelopment assessment

	Environmental	**Economic**	**Social**	**Physical**
Site level	Air pollution	Output potential per land unit	***Employment***	Flexibility of land use
	Energy consumption	The average price of properties	Impact on cityscape	Distance to CBD
	Hazardous waste	Costs of proposed de/redevelopment	The hidden danger to safety	Distance to the transportation network
	Water quality	***Payback period***		***Distance to public services***
	Noise pollution			Connection with R&D
Regional level	Air quality	GDP per capita	***Residence density***	Brownfields reused percentage
	Water quality	Disposable income per capita	Population structure	Green spaces per capita
	Energy neutral status	***Employment level***	Residential area per capita	Balanced land use
	Soil condition	Labour productivity	Regional reputation	Ongoing construction percentage
	Waste production	Expenditure on R&D		Redevelopment efficiency
	Noise pollution	Housing price/rent index	Average educational level	
			Spatial segregation	Innovation level
			Accidents level	***Other land uses percentages***
			Population under poverty	***Accessibility to work and services***
			Crime level	

The bold and italic indicators are either calculated or visualized incase the specific number cannot be obtained. And some other extra indicators are also calculated to show the possibility from various data sources. For each of the indicators applied, interviews should be conducted using questionnaires with experts to find suitable weights for each indicator.

This sustainability assessment framework is in line with the case representation structure presented in section 3.4.4. In other words, each indicator and the attributes that reflect these indicators need to be calculated before the industrial site redevelopment and after the transition. As a result, the redevelopment impacts can be assessed by comparing the attribute value changes. On the other hand, the indicators reflect regional and site level statistics from four aspects, namely environmental, social, economic and physical aspects which are all used in representing cases as illustrated in section 3.4.4. To conclude, the sustainability evaluation framework shares the same essence with the proposed case representation structure.

Within these attributes that we can calculate to reflect regional and site level sustainability indicators, feature selection procedure is performed to find the most important attributes in determining which transition form one industrial site would probably take from the known cases. Several algorithms from machine learning have been assessed, including simple tree, bagged tree, CHAID, and self-organizing maps (Kanevski et al., 2009). The most important attributes that can determine the transition forms with the highest accuracy are chosen, so as the algorithm, for the test set. The test set includes all the transformed industrial parcels in the first two years, and cross-validation is applied to reduce overfitting problems. These attributes are going to be used to construct the online tool for participatory planning.

3.4.8 Similar case retrieval

The following equation is used to calculate the similarities between cases. This equation is readily applicable to quantifiable attributes. Qualitative attributes, such as visions, are mapped to semantic vector space first in order to be comparable. In this research, weights for different attributes to indicate the importance of visions are set manually.

$$\sqrt{\sum_{i}^{N} w_i \left(\frac{a_i - b_i}{\sigma_i}\right)^2}$$

Where:

i: the i^{the} attribute;

N: number of attributes;

w_i: weight for attribute i;

a_i : attribute i value for case a;

b_i : attribute i value for case b;

$a_i - b_i$: similarity of attribute i between case a and case b;

σ_i : standard deviation for attribute i.

3.4.9 CBR in urban planning conclusions

To support sustainable industrial site redevelopment for a region, CBR is applied. Firstly, the requirements and proposed solutions are illustrated. The specific implementation process for industrial site redevelopment planning is presented, together with the designed case presentation structure so that impacts of industrial site redevelopment plans can be quantified and further evaluation is possible. To serve this purpose, data collection requirements are also listed. In addition, based on the structured case representation approach, regional political and private interests can be better presented. Zoning plan documents are applied to finding more details from each past experience. An approach is presented for semi-automatically finding regional specific redevelopment interests. Natural language processing method is proposed to analyze long zoning documents. Important attributes for each region is identified using regional specific data and characteristics. Besides regional visions, quantifiable attribute values are also used to represent each case, and the most important ones for each regional industrial site transition are identified using machine learning techniques. Similar case retrieval algorithm is presented using the presented case representation structure.

3.5 Land use simulation

Based on the literature review in Section 2.4, it is important finding a generic way to set neighbourhood rules using vector data and incorporating land use transition impact analysis. It should also be possible to explain the method to the users transparently. Land use modelling should have an empirical foundation. By means of empirical study, rule settings ought to be tailored to individual regions. In this research, a generic semi-automatic approach for neighbourhood rule discovery is proposed. It uses vector maps to minimize the information loss. A cellular automata land use change simulation model is then constructed based on regional land use change analysis and calibration results. To make the process easier to explain, the industrial land transition process is used as an illustration. Providing that industrial site redevelopment process requires detailed information of feature shapes, vector shapes of parcels in land use maps are applied. A generic algorithm to calculate land use percentage changes in various buffer zones is utilized to detect the impacts of the changes, using vector shapes. Section 3.5.1 in detail illustrates how we have applied computers to semi-automatically construct such land use change simulation model and the procedures we have used to analyze regional land use changes. A regional specific land use change model is constructed, and a specific redevelopment analysis for regional industrial land change is within reach. As a result, land use change analysis and simulation model construction become less tedious and more applied by other regions. The proposed approach can analyze the inertia for one land use type to stay, the attractiveness of surrounding land uses to one land use type to appear, the impacts of one transition on the surroundings and eventually derive neighbourhood rules for land use change simulation. The neighbourhood rules are derived based on data analysis and interpretation. Thus, it illustrates the applicability of the proposed approach with transparency and the time-saving in setting initial neighbourhood rules. METRONAMICA is chosen as the most suitable platform for this research because of the relatively small amount of data required, relatively large number of land use types can be handled, possibility to prioritise specific land uses and ease for generating maps for communication purpose. The METRONAMICA platform, which is developed by RIKS (van Delden et al., 2011) has been used for several studies (Hewitt & Escobar, 2011; Schetke & Haase, 2008). It uses a constrained cellular automata approach to simulate future land use changes by calculating the transformation potential for each cell. There is also a document illustrating the calibration procedures (RIKS, 2012), compared with a benchmark model.

3.5.1 Neighbourhood rule discovery process

The neighbourhood rule discovery process is presented in Figure 3.5.1.1. The automatic part contains the *developed FME®* ("FME Workbench Transformers FME Desktop 2015.1," 2015) and *Python®* ("Python v2.7.5 documentation," 2013) *scripts* to manipulate vector data and visualize neighbourhood percentage changes. The manual process uses the calculated percentage changes to derive neighbourhood rules. The derived neighbourhood rules are applied in the land use change model. The approach is validated by comparing the *calibration* results of the proposed model with a benchmark model. The generic way to set neighbourhood rules using vector data and incorporating land use transition impact analysis is designed based on the following concerns. Parcels with changed land use are identified from three-year land use data. Parcel geometry can be changed either due to precision errors or due to actual redevelopments. In order to relate parcels with altered geometry, the intersection of parcels from all three years is stored in features that carry the attributes of the originating features. This is performed by *overlay analysis*. Prior to this step, polygon vertices are 'snapped' in order to eliminate tiny features originating from precision errors. Based on a *combined land use codes* generated from these three years, features that have changed can be automatically identified. *Buffer* function is applied to set buffers from the edge instead of the centre to keep the original parcel shapes. A range of buffers with increasing radii is constructed to find the decay curve for the neighbourhood rule influence. *Relating features* in various buffer zones are identified using spatial relators.

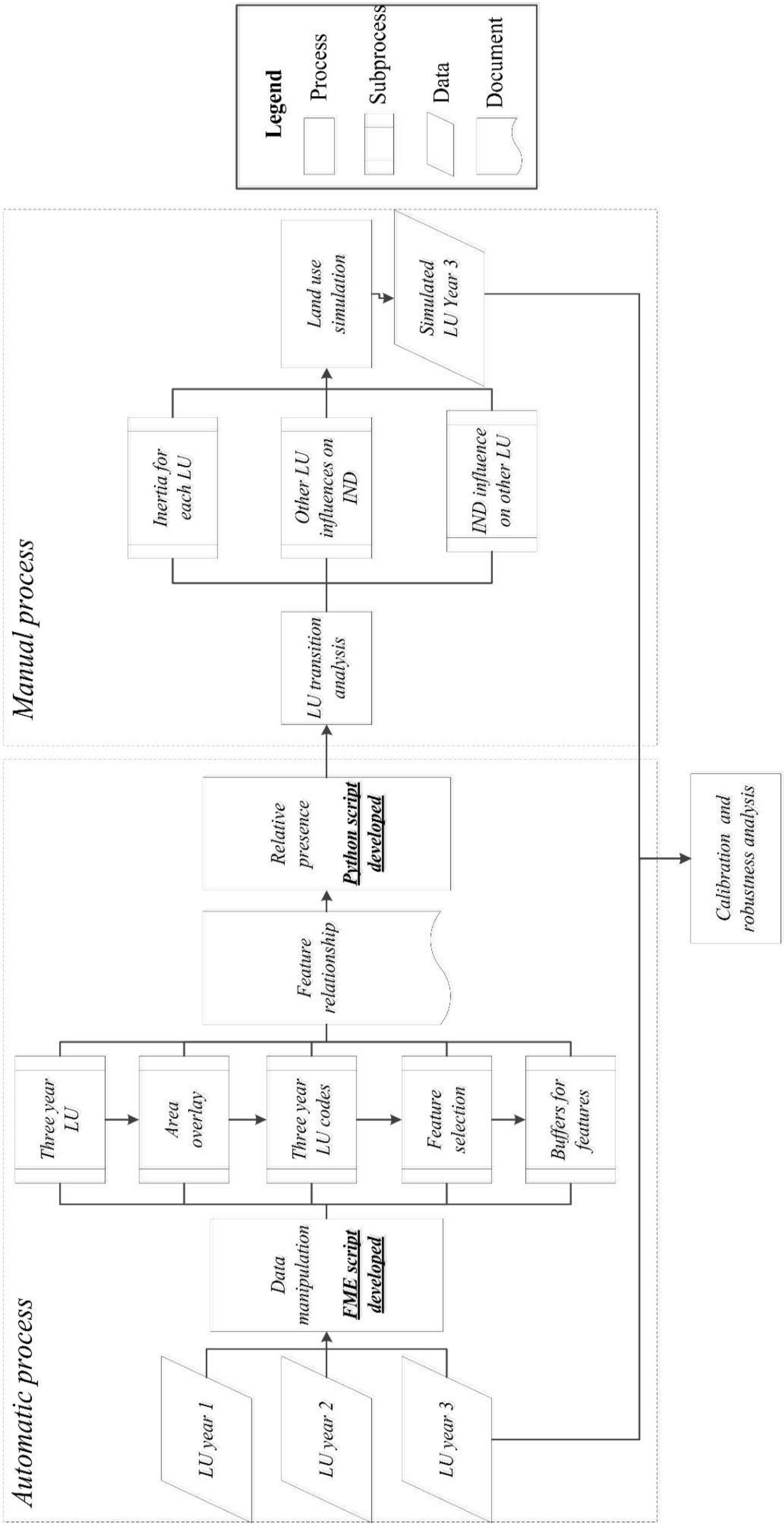

Figure 3.5.1.1. Neighbourhood rule discovery process

Additionally, neighbourhood feature sizes are considered for determining the impacts of such relating neighbouring features. Regional distribution of each land use is also put into the account. The sizes of neighbouring features and regional land use distribution are calculated by GIS spatial analysis tools. In our research, *land use data* is from three years. For the industrial site that stays the same, three-year land use information is used to accumulate more information to analyze their surroundings. For appeared industrial sites, the difference between the year 1 and year 2, the difference between the year 2 and year 3, and the difference between the year 1 and year 3 are all considered, so as the disappeared industry sites. The disappeared industrial sites that are detected by the difference between the year 1 and 2 are used to check the influence of such transition in the surroundings in the year 3. In the land use change simulation model, the year 1 and 3 as the starting and ending year respectively, with two years as interval step.

In the data preparation phase, an *FME® script is developed* for the automatic manipulation of vector land use maps. Other regions can apply our tool easily. The script is developed with Safe Software FME® Desktop version 2015.1.0.1 (*FME desktop*, 2016). FME® is a visual programming environment in which spatial data can be manipulated by transformers that affect either geometry of features or their attributes. In the first step, *three-year LU maps are combined* to generate a single *multiyear LU map*. This ensures that the land transition effects can be traced. This is followed by several steps to clean and prepare the data for the use case at hand. The snapper transformer is used to bring end or vertex points of features together to eliminate geometry errors. Areas are *overlaid* where they intersect and then merged into an additional feature that carries the attributes of the originating features. These two steps assure that information on the different years is accumulated into the same feature, regardless of inaccuracies in the data. *Land use codes of three years* are combined by function 3.5.1 to create a unique code for each land use configuration. The numbers 10,000, 100 and 1 are chosen to make sure that adding up numbers would not end up with the same code for different combinations. Since the biggest land use codes in this study is 24, it is no problem to multiply these codes to 100.

$$\textit{Combination LU} = \textit{LU (year 1)} * 10{,}000 + \textit{LU (year 2)} * 100 + \textit{LU (year 3)}, \quad (3.5.1)$$

Further on, a dissolver function is applied to remove common boundaries between neighbouring areas with the same aggregated land use code. After these steps, areas created as artefacts are removed. Furthermore, only areas larger than 10,000 square meters are retained. One reason is that later 100 meters resolution is used in the proposed land use model. This resolution comes close to the actual size of building blocks in the Netherlands and allows for the use of homogenous cells that only describe the dominant land use (van der Hoeven, van der Klis, & Koomen, 2009). Another reason is that this reduces computation time. This process is called *feature selection*.

In many CA land use models, the circular neighbourhood of White and Engelen, which has a radius of eight cells, is applied. This is especially the case for regional planning (Abolhasani et al., 2016; Basse et al., 2014; White & Engelen, 2000; White et al., 1997). Given the resolution of 100 meters used throughout this research, around each of the industrial features in the dataset, eight *buffers for changed features* from 100 meters to 800 meters are created. This research is only to illustrate the applicability of the proposed generic approach to discover neighbourhood rules, other resolutions and neighbourhood settings can also be applied to the approach. The features, which overlap with the buffer area around the industrial feature, are considered to be in the surroundings of that industrial feature. Total areas are aggregated by adding up these related features' areas. Here features represent parcels. The algorithm to calculate these relationships is as follows:

A: =Features with one or two years of industrial land use (and area > 10,000 sq m)

B: =All features with area > 10,000 sq m

Cr,a: =Buffer areas with radius r {100m, 200m, ... 800m} for each $a \in$ A

For each $b \in B$ and each $c_{r,a} \in C_{r,a}$

If $b \cap c_{r,a} \neq \emptyset$ and $b \cap c_{r-1,a} = \emptyset$

Then b is related to a in radius r

In order words, if one feature intersects with a buffer zone of an industrial feature, it is recorded as a *related feature* to the industrial feature if and only if it is not completely encapsulated in a smaller buffer zone around that same industrial site. Two configurations of spatial-relators are used to fulfil this algorithm in FME®. The first configuration assesses the features intersection with a certain buffer radius. The other configuration is in place to exclude features completely embedded in a smaller buffer zone. These features' effect needs to be deleted since they are already calculated in the previous smaller buffer area. Figure 3.5.1.2 provides an illustration of this algorithm for an industrial site (IND). Feature 1, 2, 3 are in the radius of 100 meters of the IND, while only Feature 2 and 3 are in the radius of 200 meters of the IND since feature 1 is completely located in 100 meters radius of the IND.

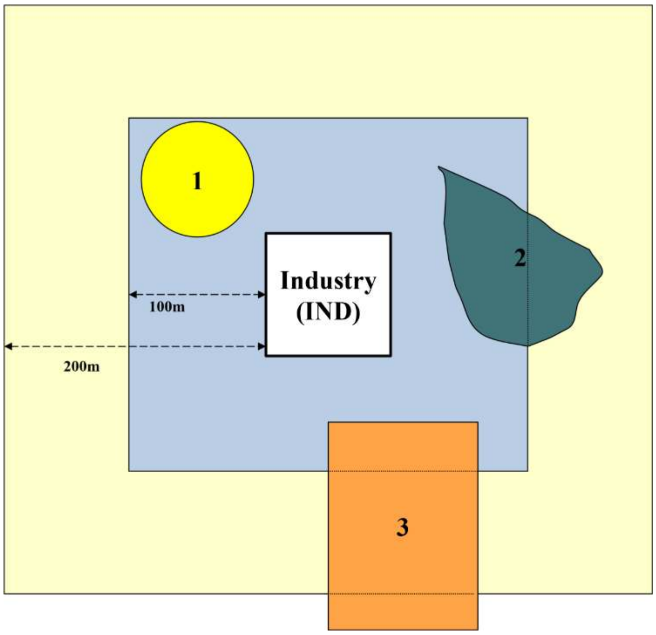

Figure 3.5.1.2. Illustration for the algorithm and percentage calculation by keeping feature shapes. (IND: industrial site)

Figure 3.5.1.2 also shows the calculation of the *relative presence* percentage process.

For IND, in 100 meters radius, Area (i) represent the size of feature i:

Percentage of Feature 1 = (Area (1))/(Area (1) + Area (2) + Area (3)), *(3.5.2)*

Percentage of Feature 2 = (Area (2))/(Area (1) + Area (2) + Area (3)), *(3.5.3)*

Percentage of Feature 3 = (Area (3))/(Area (1) + Area (2) + Area (3)), *(3.5.4)*

For IND, in 200 meters radius:

Percentage of Feature 1 = 0, *(3.5.5)*

Percentage of Feature 2 = (Area (2)) / (Area (2) + Area (3)), *(3.5.6)*

Percentage of Feature 3 = (Area (3)) / (Area (2) + Area (3)). *(3.5.7)*

Comparing function (3.5.2) and (3.5.5), it is clear that the influences of feature 1 towards IND are only considered in 100 meters' radius, not in 200 meters' radius, following the same algorithm. As a result, features like Feature 1 that are completely embedded in a smaller buffer zone (100 meters here) are deleted from a larger buffer zone (200 meters) since they are already calculated in the previous smaller buffer area. In Figure 3.5.1.2, this means that Feature 1 is deleted for buffer zone 200 meters since it is completely embedded in butter zone 100 meters. However, feature 2 is still considered to be in the buffer zone 200 meters since it is not entirely embedded in the buffer zone 100 meters. Double counting effects are therefore eliminated. Performing this Boolean exclusion turned out to be infeasible in FME® visual programming logic. For this reason, a *Python® script is developed* to emit plain text files recording these two types of relationships which are later used for calculating the percentages in the surroundings. Aggregating and visualizing the results are accomplished in the Python® script in version 2.7.5.

The regional distribution of land use is also put into consideration. This is a normalization process in which the local prevalence of a land use type around a target land use type is compared with the general prevalence of this land use in the entire region. Continuing with the example from Figure 3.5.1.2, the expected percentage of all the features with land use type 1 (in other words, regional distribution of features with land use type 1) in the whole region is calculated as a function (3.5.8). The total area here represents the sum of all the features meeting defined requirements. For example, Total area (1)(Features > 10,000) represent the total areas of features with land use type 1 and are bigger than 10,000 square meters :

$$\text{Expected Percentage (1)} = (\text{Total Area (1) (Features}>10{,}000)) / (\text{Total Area (Features}>10{,}000)), \quad (3.5.8)$$

Surrounding characteristics of one land use type (in this case land use type of feature 1) for IND can be calculated without the impacts of its own distribution influences according to formula (3.5.9). Values above 0 represent positive influence between land use type of feature 1 and IND and vice versa.

$$\text{Relative Presence (1)} = (\text{Percentage (1)} - \text{Expected Percentage (1)}) / (\text{Percentage (1)} + \text{Expected Percentage (1)}), \quad (3.5.9)$$

Industrial site *land use transition analysis* is used as an illustrative example. Other land use transitions can also be calculated and analyzed in a similar way. The first analysis is for land uses stay the same. This can tell the *inertia for each LU*. Secondly, the appeared industrial sites are analyzed. Graphs are generated automatically by the developed Python® script, which shows the surroundings before and after new industrial sites appeared. These graphs show the attractiveness and repulsiveness of other land use types on industrial sites to appear within various buffer zones. This analysis sets neighbourhood rules for the *other LU influences on industrial land* in the land use change model. Furthermore, the impacts of industrial site conversions on the surrounding land uses are analyzed by comparing the surrounding land uses percentage changes before and after the transitions. The generated images from our Python® script can visualize the differences. This step is used to set neighbourhood rules for *industrial land impacts on other land uses*. After these several steps, a *land use simulation model* can be constructed. The *simulated LU maps for year 3* can be then compared with the actual land use map from year 3. *Calibration* is applicable. *Robustness* analysis can also be performed by applying this approach to sub-regions of the region.

3.5.2 Metronamica and its benchmark model

There are several CA platforms for land use change simulation exercises. In this research, Metronamica is applied for the illustration and validation of the approach. Metronamica is a generic forecasting platform developed in the dynamic modelling environment GEONAMICA® to simulate and assess the integrated effects of planning measures which incorporates a constrained CA model ("Metronamica documentation," 2012). Metronamica version 4.3.2-beta 1 is used for applying the rules generated from the analysis to simulate land use changes. The user-friendly interface makes it easy to change neighbourhood rules. Metronamica comes with a naïve land use predictor with pre-set rules ("Metronamica documentation," 2012, pp. 102–107) which only models land use influences on themselves from different distances. For example, at a distance 0, the self-influence is high with a value of 100 as it models the extent to which a type of land use is likely to remain unchanged, the so-called inertia. When distance increases to 100 meters, this self-influence is still positive but set to a much lower value of 1. For 200 meters, no influence is modelled since this would cause high turbulence (van Delden et al., 2005), regarding the number of parameters included in the land use change model. Land use interactions are not modelled in this naïve predictor. For example, the influence of industry on housing is not modelled. This predictor model is considered as a benchmark to compare with the proposed land use model which uses rules derived from the semi-automatic discovery process. These rules contain both land use self-influence and land use interactions.

Other land use simulation platform like land use scanner (Koomen, Hilferink, & Beurden, 2011) can also be applied, and results can be compared. After all, the proposed approach with the tools associated with deriving neighbourhood rules can be considered as a plug-in or a standalone toolset. Several tools are developed to make the CA model calibration process quicker such as the Map comparison kit (MCK) (*Map Comparison Kit*, 2006; Visser & de Nijs, 2006) embedded in Metronamica. MCK is used to compare the proposed model and the benchmark model.

In this section, a semi-automatic neighbourhood rule extraction approach is presented. It will be later applied to the case study region in Chapter 4 to construct regional specific land use change simulation model and the calibrated model is used to incorporate new designs for the selected target site to simulate future regional land use simulation. This is used to evaluate regional sustainability and future land use situations. Detailed regional industrial land transition analysis is also presented in Chapter 4 to show the regional characteristics of industrial site transition for the case study area. This analysis is used to illustrate the use of such analysis for helping land use simulation modelling.

3.6 Sustainability evaluation

Many sustainability assessment methods like EU standard framework, Dutch standard framework, and other sustainability assessment systems like LEED for buildings are reviewed for selecting suitable indicators based on our goal setting and industrial land use reclassification. A matrix is made of the selected indicators. The matrix is constructed based on two disciplines. One is social, economic and environmental discipline, while the other is site and region scale discipline. The selected indicators are allocated in the matrix as shown in Table 3.4.7 based on these two axes, and with a concern of tempo-spatial oriented criteria.

As explained in the literature review part, indicators should be selected based on the following criteria: firstly, they should reflect economic, environmental, social and physical changes; secondly, they should combine both site and regional level sustainability assessment; thirdly, indicators should have both temporal and spatial attributes; fourthly, the selection of such indicators should be a repetitive process together with policymakers. The selected indicators also have gone through validation with the currently used sustainability evaluation framework used by the selected regional authority for industrial site redevelopment.

Based on the selected industrial site for redevelopment from section 3.3 and the chosen strategy from section 3.4 and the land use simulation result from section 3.5, indicators values are calculated based on related attribute values and presented to assess regional and site level sustainability. More detailed explanation about this part is presented in Section 4.6 by combining case study results with the framework presented in section 3.4.7.

3.7 SIRPSS summary

SIRPSS combines top-down scenario analysis with the bottom-up site design. As a result, macro-level regional planning process by planners and micro level site designing by individual land users are both implemented. Incorporating the design concept into this planning support system gives a holistic approach to solve complex problems from both sides of the stream, taking stakeholders into account. Thus, the system is not only policymaker oriented, but also individual user-focused, providing mutual benefits.

Talking about the date integration module, to start the system, multiple data from land use maps, building information, zoning documents and other social-economic data are integrated into the data integration module. Specifically, for sustainable industrial site redevelopment, a focus is put on facility reuse. To facilitate this requirement, building information modelling and GIS are integrated using a loosely coupled way.

An implementation framework for using CBR in urban planning problem is presented in section 3.4.2. Specifically, for industrial site redevelopment, transition forms are introduced, so as visions for redevelopment. They are used to combine transition preferences with land use simulation modelling. Detailed information can be found in section 3.4.3. As a result, a hierarchical case representation structure is presented in section 3.4.4. Data collection requirements are listed afterwards. To extract visions for regional industrial site redevelopment, tools are developed and explained in section 3.4.6 using zoning documents and land use maps. The constructed redevelopment land use case base is augmented by quantifiable attribute values which represent sustainability. The most essential sustainability-related attributes are identified using machine learning techniques and used for similar case retrieval in section 3.4.8.

To incorporate the newly designed industrial site into regional land use modelling practice, land use simulation models are constructed using CA modelling technique. Tools are developed for neighbourhood rule extraction based on three-year vector land use data, with a focus on land use transition analysis. With the help of the tools developed, the land use model can be calibrated based on historical data. The simulated land use map is compared with the actual land use map from the third year. Only when the comparison gives a satisfactory accuracy, the model can be used as a calibrated land use change model. The calibrated land use model is used to simulate future land use change while applying the newly designed industrial site. This helps to evaluate future regional and site level sustainability.

The proposed system also incorporates sustainability indicators' evaluation from four aspects namely social, economic, environmental and physical aspects. It is a dynamic system which focuses both on the short and long-term impacts of the redevelopment plan.

CHAPTER 4 CASE STUDY[8]

In this chapter, the case study area is firstly presented, together with data sources. Later suitable sites for redevelopment based on the requirements from public and private parties are found using both GIS data and building level data. The suitable site for redevelopment is then presented with the proposed case representation structure so that the system can retrieve similar cases from the past. Similar cases are then presented to the user to see what the options for the new site from the past are. After determining what option the new site is taking, the zoning plan is incorporated into land use simulation model so that future sustainability can be evaluated based on not only site level but also regional level indicators. This chapter follows the structure as presented in Figure 3.1.3.

4.1 North Brabant

The North Brabant region has been chosen as the case study for its sustainable ambition and the industry and research-oriented regional characteristics. Many industrial sites in this region have been redeveloped since the 21st century because of the limited land resources. In this research, land use data from the year 2000, 2008 and 2012 are used. The disappeared industrial sites between the year 2000 and 2008 are used to check the influence of such transition on the surroundings in the year 2012.

4.2 Data collection and integration

4.2.1 The data flow of SIRPSS

Regarding data usage within SIRPSS, a more detailed data flow image is presented in Figure 4.2.1. in which data from various sources are combined in different steps of the application. Apart from the previous research flow in Figure 3.1.3, this chart emphasizes on the usage of various data sources for each process in the research flow chart.

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[8] Modified based on: Wang, T., Han, Q. & de Vries, B. (2018), SIRPSS-Sustainable Industrial Site Redevelopment Planning Support System, F. Dargam et al. (Eds.): ICDSST 2018, LNBIP 313, pp. 1–12, 2018. https://doi.org/10.1007/978-3-319-90315-6_1

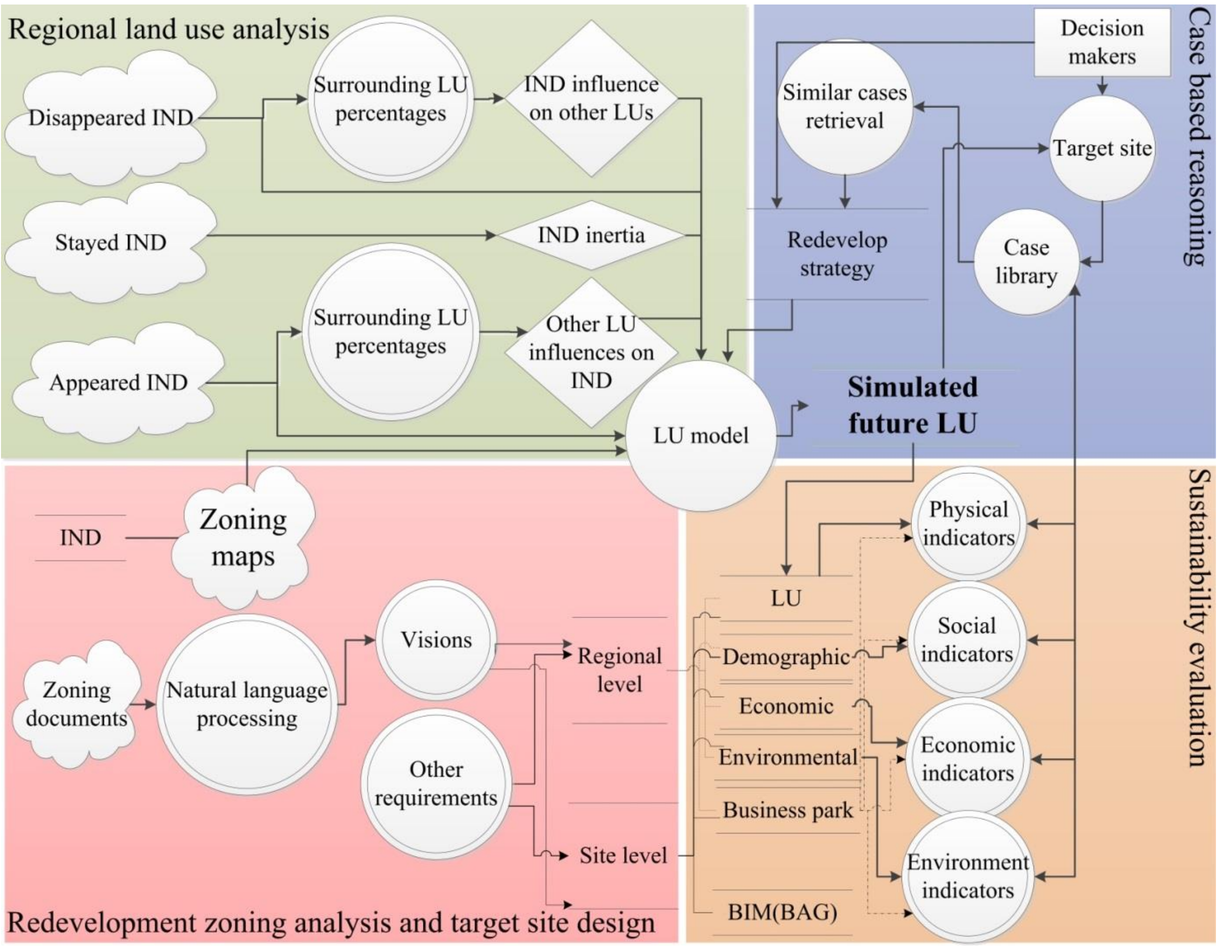

Figure 4.2.1. Data flow for SIRPSS (IND: industry; LU: land use, BIM: building information, BAG: building address registration)

Land use (LU) data is analyzed to find the industrial transition in three scenarios, namely *appeared industry, stayed industry and disappeared industry*. Specifically, by analyzing the physical *surrounding land use percentages* change for each of these scenarios, *other land use influences on industry (IND), industry inertia* and *industry influence on other land uses* can be quantified. As a result, a *land use change model* is constructed. *Historical zoning documents* are analyzed by *natural language processing* tools so that regional characteristics of redevelopment *visions* are identified. *Land use, demographic, economic, environmental, industrial* and *building info* data are integrated so that based on regional *visions* and specific requirements for *other attributes* from *regional level* and *site level*, the most suitable redevelopment sites can be identified (*target site*), so as past *similar cases* and the associated *redevelopment strategies*. Their designed impacts and accomplishments are projected to the new industrial site and imported into land use simulation model to model future *land use* compositions after the new redevelopment. As a result, dynamic evaluation of sustainability indicators becomes possible. Four types of indicators are included in the evaluation, namely *physical indicators, environmental indicators, social indicators* and *economic indicators*. They are on both *site level* and *regional level*. The following sections explain the data sources for each category in the case study area.

4.2.2 GIS and building data

GIS data includes land use maps (Centraal Bureau voor de Statistiek & Kadaster, 2003, 2006, 2010) and Nationaal Georegister ("Bestand Bodemgebruik 2012 shape file," 2016), zoning maps ("Documentatie bij het GIS bestand van de Nieuwe Kaart van Nederland," 2010), IBIS (Nijssen & Kremers, 2013) and BAG (Kadastre, 2017) data. They are found from DANS (DANS, 2012), Nieuwe kaart van Nederland (Nirov, 2010), North Brabant databank (Provincie Noord-Brabant, 2012) and PDOK (PDOK, 2016) respectively. These data sources provide download links for professionals to download datasets they need. IBIS data (ARCADIS, 2014) reflects business park site-specific data, in which industrial activities, employee's structure and each activity area size, whether the business park is vacant and to what extent information is stored. This helps to find later suitable redevelopment sites based on the regional policymakers' visions and specific requirements for a site from actual future users. PDOK service (PDOK, 2016) provides other demographic information such as how many people are living within a certain radius from the industrial sites, what the population composition is, how many public facilities are nearby, what the income structure is. Zoning maps are the dataset which includes zoning maps for each site of the region.

Building information models are not available currently on the regional level. As a result, only limited information about buildings is retrieved from BAG data (Kadastre, 2017) which represents basic registration data for addresses. Even though people can argue that BAG data at this moment is also GIS-based, it is used to illustrate the use of building information in the system to facilitate facility reuse on abandoned industrial sites since BAG data contains information on activities for each building and floor area for each industrial activity from building information.

In SIRPSS, facility reuse is emphasized for further regional redevelopment tasks in the following case study. As a result, building information that can determine facility reuse is added to the system such as floor area, vacant size and so on. GIS and BIM data sources are combined for facility reuse purpose without converting data formats.

4.2.3 Other data

Other data including but not limited to economic, environmental and demographic data are mainly from CBS and national geography databank. A particular data source is SBI codes from BAG which is further explained in 4.2.4. They are included in the system because they represent the industrial activities for each building. As a result, building level information is also aggregated into the data integration module. On the other hand, this also makes the research more industrial site related to incorporating industrial activities in each facility into the analysis.

4.2.4 SBI codes

SBI codes are the activities codes for Dutch industry (Centraal Bureau voor de Statistiek, 2017). They present the functions for each company in a building. SBI codes are used to integrate building information into GIS data so that more detailed description of past cases and the new site can be achieved. Detailed SBI codes are listed in Appendix B. They are categorized first so that similar activities are put together. These codes are used to calculate floor areas for each industrial activity in an industrial site. Based on these numbers, site characteristics can be more precise regarding industrial activities, and suitability calculation for redevelopment and similarity between cases can be better performed, regarding industrial activities. Moreover, SBI codes can show detailed information on what function or industrial activity has been removed and what other functions are added later in the past experience and can also reveal whether the site is contaminated to some extents. For example, a site with an SBI code representing heavy metal industry is probably not suitable to be transformed into housing or other sensitive functions later, even though there might be past experience that suggests this type of transition. In the Netherlands, other sources can also be used to determine the suitability of sites for different redevelopment options, such as milieuvergunningen and omgevingsvergunningen (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2018). However, these two sources are not included at this moment in the implementation due to the time limits.

4.3 The target site

To illustrate the applicability of the system, one site based on the suitability calculation from limited data sources is applied. This target site is also used to match with our constructed case library to find similar cases from the past. As a result, suitable redevelopment strategies to the new site can be found from past experiences. The suitability for redevelopment of the whole regional industrial sites are calculated based on geospatial data and building information for the facilities on each industrial site. Accordingly, supply side and demand side can be combined as explained in section 3.2 and 3.3. Because of the data collection limitations, the illustration is with constrained data. According to the proposed approach to integrate GIS and BIM data, building information models for each facility should be available for all the industrial sites in one region. However, this is not possible at this stage of the development. To fulfil the illustration purpose, IFC models are not used, but instead, geospatial datasets which contain building information are applied. As a result, building information data only includes building activities, floor area, and vacant floor area for each categorized SBI code. When there is more data available, the system can be better demonstrated, so as the proposed GIS and BIM integration framework.

A proof of concept example is presented in the case study section. The weights are assumptions, and only limited number of attributes is included in the calculation for redevelopment suitability including distance to highway, to bus stops, to the airport, to railways; available land for redevelopment for each site; green area affected. Other attributes based on building information such as to be demolished building areas, total floor area and each site main business activities (SBI codes) are also listed. CommunityViz (Placeways LLC, 2013) is applied to calculate these attribute values and integrate all data sources into a GIS environment. For each of the attributes, the weight is given based on the assumptions that for this specific region, the emphasis would be on reuse of existing buildings. As a result, high weights are given to total floor area and unused buildings for each industrial site. Table 4.3 gives an overview of the attributes used and the weight assumptions for them based on the current industrial site redevelopment vision of facility reuse. As a result, a list of suitability scores is achieved and suitable sites can be selected based on the suitability scores which combine both GIS information and BIM information, according to the weight assumptions in Table 4.3. The weights are assumptions and users can also choose which attribute is an essential hard requirement and which can be switched off.

Assuming the redevelopment vision for the individual developer is to invest less, and the government wants more facilities to be reused (according to the new BIM trend for facility reuse), and the transition should be coherent to the surrounding geospatial environment. Based on the current suitability analysis, more weights are given to the unused building areas and total floor areas. As a result, Figure 4.3 shows the most suitable site for redevelopment based on the current attribute weight setting, for more facility reuse requirement. This site is near Halsteren, and detailed information of this site is listed later in Table 4.4.2. We name this site "Target site". The location of this site in the whole region can be seen from Figure 4.5.8.

Table 4.3. Weight assumptions for used attributes to calculate redevelopment suitability

Attribute used	Weight assumption
Ambulance reports	0.019
Distance to airport	0.004
Distance to bus stop	0.019
Distance to highway	0.019
Distance to railway	0.019
Fire reports	0.019
Green area affected within 200 meters buffer zones	0.023
Sbi1 area	0.089
Sbi2 area	0.089
Sbi3 area	0.031
Sbi4 area	0.043
Sbi5 area	0.043
Total floor area	0.194
Unused building number	0.388

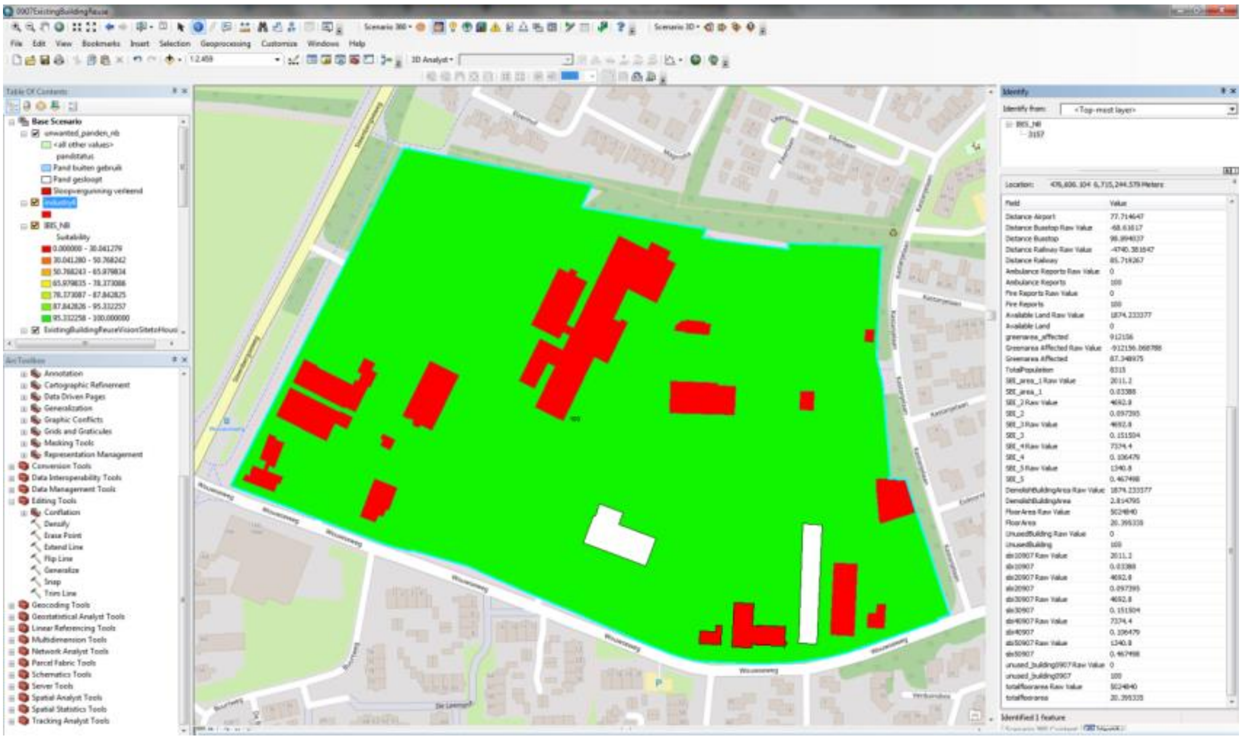

Figure 4.3. The most suitable site (Target Site) for redevelopment combining GIS and BIM

4.4 Similar cases retrieval and target site design

To find similar cases, the most important visions for each case are used. Figure 3.4.6 already illustrates the process to extract regional industrial site redevelopment visions. More detailed information regarding the case study area is presented in the following section, including the tools used, developed and the specific case study results. Safe Software FME® Desktop version 2015.1.0.1 ("FME Workbench Transformers FME Desktop 2015.1," 2015) is used to automate the manipulation processes of land use maps and zoning plan maps in the data preparation phase. A screenshot of the FME script for manipulating zoning maps and is presented in Figure 4.4.1 to give an overview of the process to find relevant zoning plans for each redeveloped industrial site. The zoning plan map contains information about zoning document for each site in a region. In other words, the zoning plans are geospatial referenced in the zoning plan map, as explained in terminology part. Firstly the zoning plan map is divided into two categories, namely the zoning plan map for the line-shape features and zoning plan map for polygon-shape features. For both of them, water areas are deleted from the dataset since they are not considered in this study. The filtered dataset is then overlaid with the industrial sites that have transformed from industry to other use, as indicated in the dataset reader "all_cases_detection_but_not_all " which only includes industrial sites that are bigger than 10,000 square meters. Once an overlap is found, these sites and the zoning plans overlapped with these sites are combined in the following procedures to create a map which connects redeveloped big industrial sites in a region to the associated zoning plans. Thereafter, a *natural language processing* tool is applied to analyze these zoning plan documents to perform text mining task for finding the most frequently mentioned visions of each redevelopment case. According to the study of all these zoning plans, several *automatic derived visions* that are mostly mentioned such as sustainable development, student housing and so on in a specific context (region) can be identified. This could be used as the basic reasoning rules for designing future similar redevelopment planning tasks. Using the same region redevelopment cases ensures the demographic and political homogeneity. As a result, each case has been described by several frequently used visions from the zoning documents. The web-service from TerMine (Frantzi et al., 2000) is used to process the texts from the previously identified zoning plan documents. Domain knowledge and semantics are necessary to provide a context for the usage of these words. As a result, *domain dependent manual selection* is performed. These case and visions relationships can be presented using computer tools. To generate the *web application* which represents cases with their used concerns in the planning documents, open source software GraphViz (Ellson et al., 2004) is applied for better visualization. In our presented graph, NEATO (North, 2004), a component of GraphViz is applied to generate the graph. It applies "spring model" layouts. This is the default tool to use if the graph is not too large and you don't know anything else about it. NEATO attempts to minimize a global energy function, which is equivalent to statistical multi-dimensional scaling. For the case study area, the translated Dutch zoning documents undergo a natural language processing procedure. After processing the documents, the visions derived from the documents are sorted according to their frequency. A total of 533 visions are listed for all processed documents. The automation process operates on a syntactic level rather than more detailed level such as a semantic level. Therefore, terms that are considered relevant to industrial site redevelopment are manually selected. The manual selection procedure ensures that the knowledge extracted is domain specific. Three types of performances are applied. The first type is to merge synonyms, and one example is “city center” is equal to “city centre”. This is a typical sort of synonyms that needs to be merged. Another type of merge is executed on hypernyms. Take this as an example. Talking about office functions, other words might also come into the document such as offices, office building, and office space. These words are merged into the hypernym which can represent all of them on a top level such as office functions. The last manipulation is to delete the commonly used words in every zoning plan document such as zoning plans, plan areas, water sector and so forth. Subsequently, 179 visions remain. Furthermore, the case base with visions, presented above, is augmented with quantitative attributes, derived from geographical calculations. However, to facilitate responsive and meaningful case retrieval, the most important attributes for determining the transition forms of industrial sites are needed for the web application. Based on the prediction accuracy result of the various algorithms, the CHAID (Kass, 1980) tree structure has been selected for constructing the reasoning path in SPSS, version 22.

The tree structure, as presented in Figure 4.4.2 shows which attributes are important and on which level of the path to determine the industrial site transition forms, in this case, industrial sites, are transformed into four categories, residential (code 20), retail (code 21) and public facilities (code 22) and social and cultural facilities (code 4). Here the main purpose is to illustrate the methods proposed instead of which algorithm should be used. These attributes are used to construct the web application as a proof-of-concept. More attributes can be added later if more data is available. Based on the CHAID tree analysis, the most important quantifiable attributes in our database are population density, area size, the biggest sellable pand in the year 2006, the percentage of households with kids, the percentage of a single person and the average number of kindergarten within 3 kilometres. These attributes produce 70% accuracy for predicting transformation forms from the year 2006 to the year 2010. The cross-validation method has been used to eliminate the overfitting.

To combine the visions and the most important attributes and to show the applicability of CBR in industrial site redevelopment, a web application is developed. Each analyzed case, as a result of this process, is associated or labelled with several visions. A web-service, operating on a smaller dataset, is given in Figure 4.4.3. To illustrate the matching of similar cases based on the visions. This website can be found on www.sirpss.com/cases (Wang, 2014).

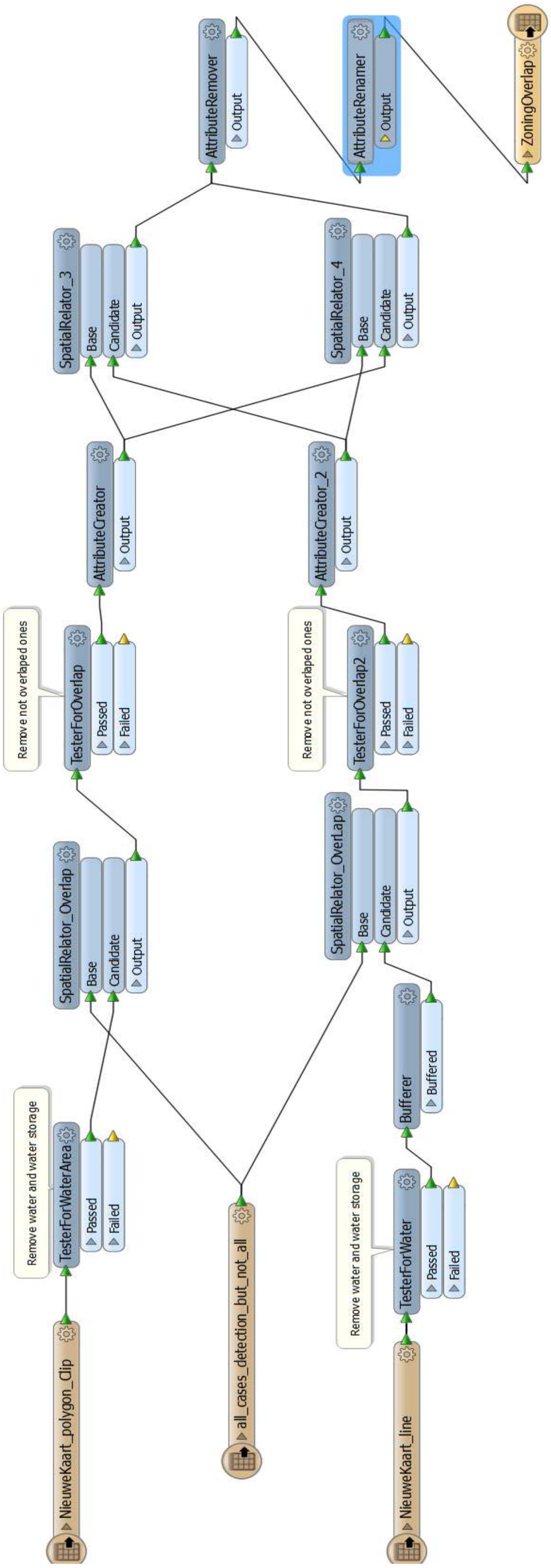

Figure 4.4.1 Screenshot of FME script for manipulating zoning maps

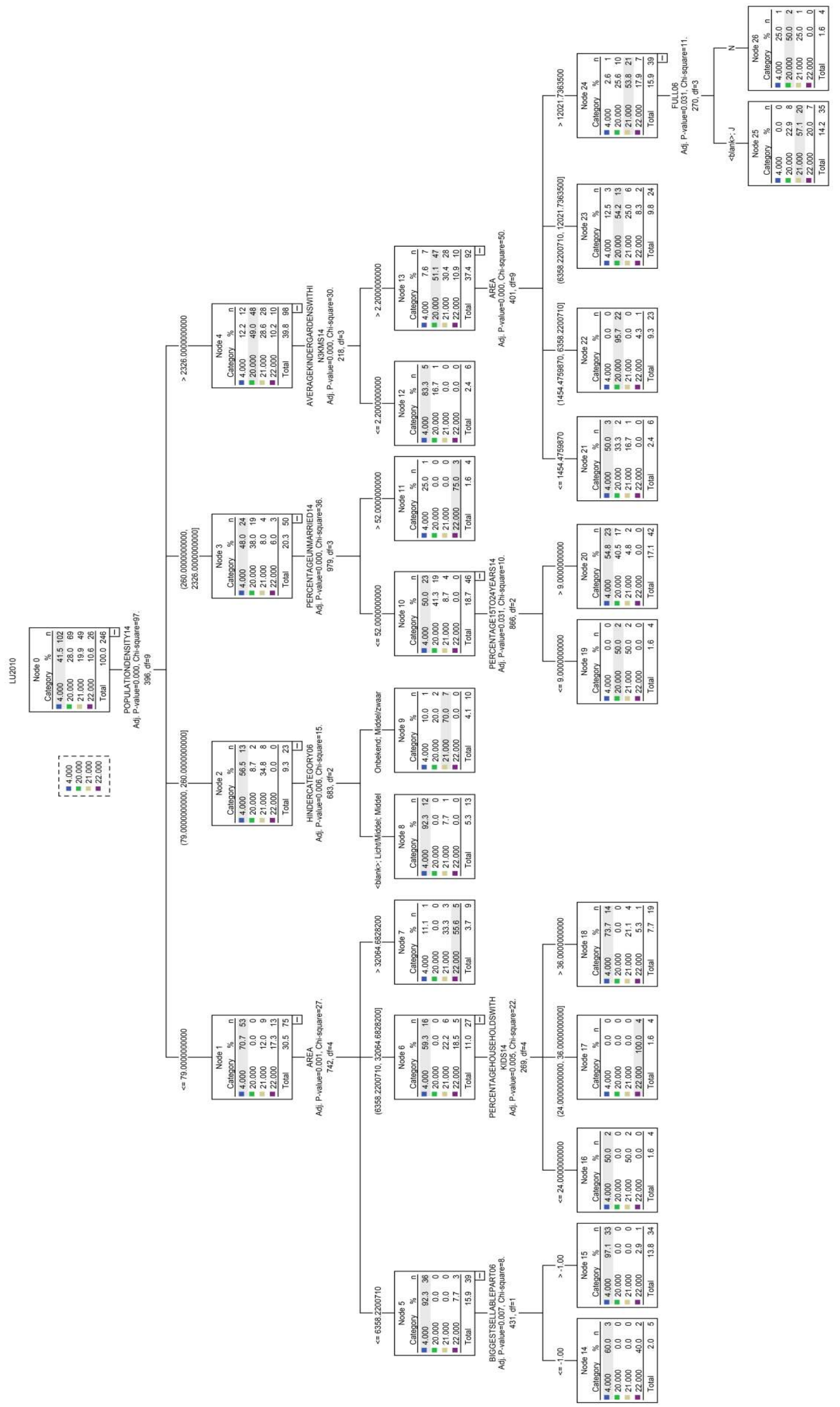

Figure 4.4.2. CHAID tree structures for determining the transformation forms

The rectangles represent the visions, and cases are rendered as elliptical nodes. The mostly used visions are more to be in the middle of the image. And the more similar two cases are, the closer they are to each other. Users can use our tool for better communication, visualization and collaboration for designing future industrial area redevelopment areas, such as finding similar cases with the same visions. Similarities and differences among various cases can be easily identified and visualized. Upon selecting a vision or multiple visions in the interface, the associated cases are highlighted with colourful labels. The greener the label is, the more similar this case is to the target site based on our calculation method which is the weighted sum of most important attribute values. Our vision for redevelopment is reuse of existing buildings (because of the new trend of using BIM for facility reuse), as we have explained in the assumption section in Chapter 1 that reusing facilities can support regionally sustainable redevelopment without much waste of materials. Drie Hoefijzers, VictoriaPark, and Lichttoren, KVL terrain and Cite Industrielle cases are found based on this single vision. The greener a rectangle is, the more similar it is to the target site based on the current weight settings.

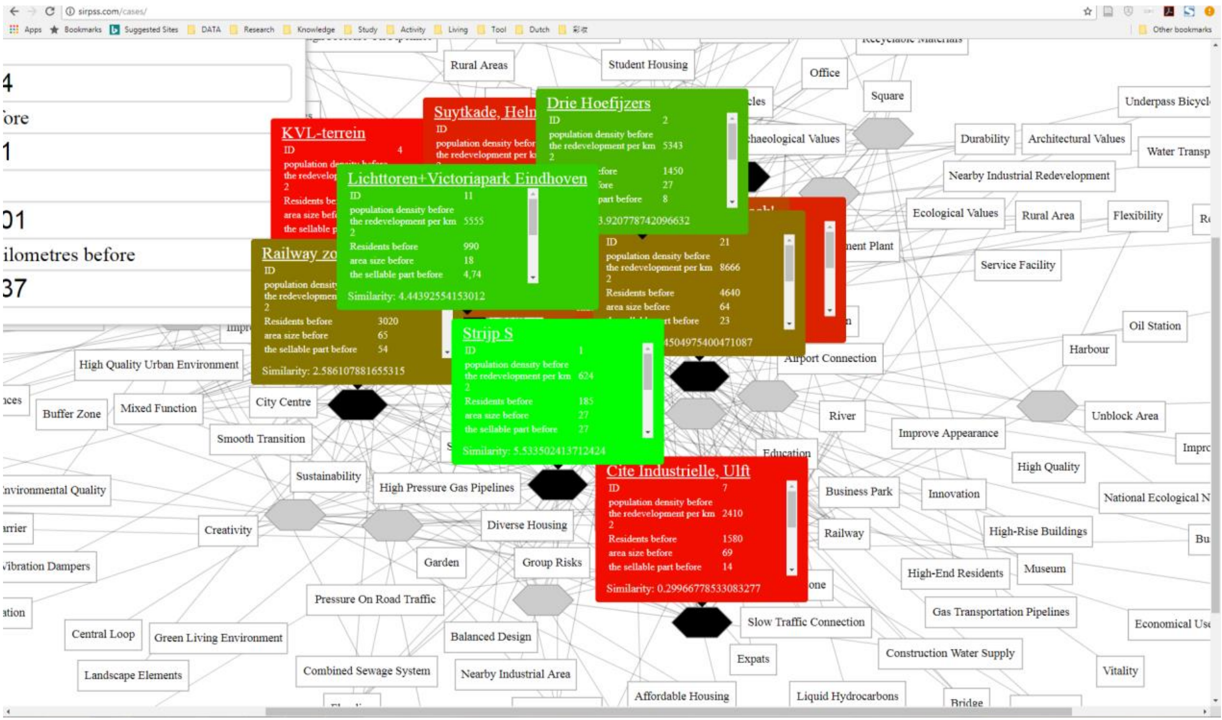

Figure 4.4.3. Redevelopment case similarities based on visions and similarity scores

The similarity is calculated based on an equation from section 3.4.8 which uses available attribute values, multiplied by the weights given by the author for each attribute, to sum up, the total similarity values for each available past case from the library, in comparison with the new selected target site. The similarity is automatically updated if users change the weight settings in the interface. More attributes can be added later based on preferences from the users. Now it is only used to illustrate the applicability of our tool. The used attributes and their weights are enlarged in Figure 4.4.4.

“Smooth transition” is also chosen as a vision here because it comes in line with sustainable facility reuse and reduces those similar cases from the case library to facilitate a more straightforward case comparison study. After selecting both Smooth Transition and Reuse existing buildings, the most similar cases are found as Lichttoren+Victoriapark Eindhoven and Drie Hoefijzers. Users can click on these two cases, detailed information is listed based on common structures of zoning plan documents, as shown in Figure 4.4.5. They come in line with the proposed case representation structure as stated in section 3.4.4. These tables are a simplified version of long zoning plans (examples can be seen in Appendix D) which include the following sections: planning area, develop principles, environmental concerns, water section, legal issues, financial arrangement, and procedures. Besides this information, other attributes are also included to show the dynamic temporal change of several important attribute values such as population density before and after the redevelopment, as shown in Table 4.4.1. Currently used attributes (not complete) that structures each case example are enlarged in Figure 4.4.6.

Figure 4.4.4. Used attributes and weights for similarity calculation

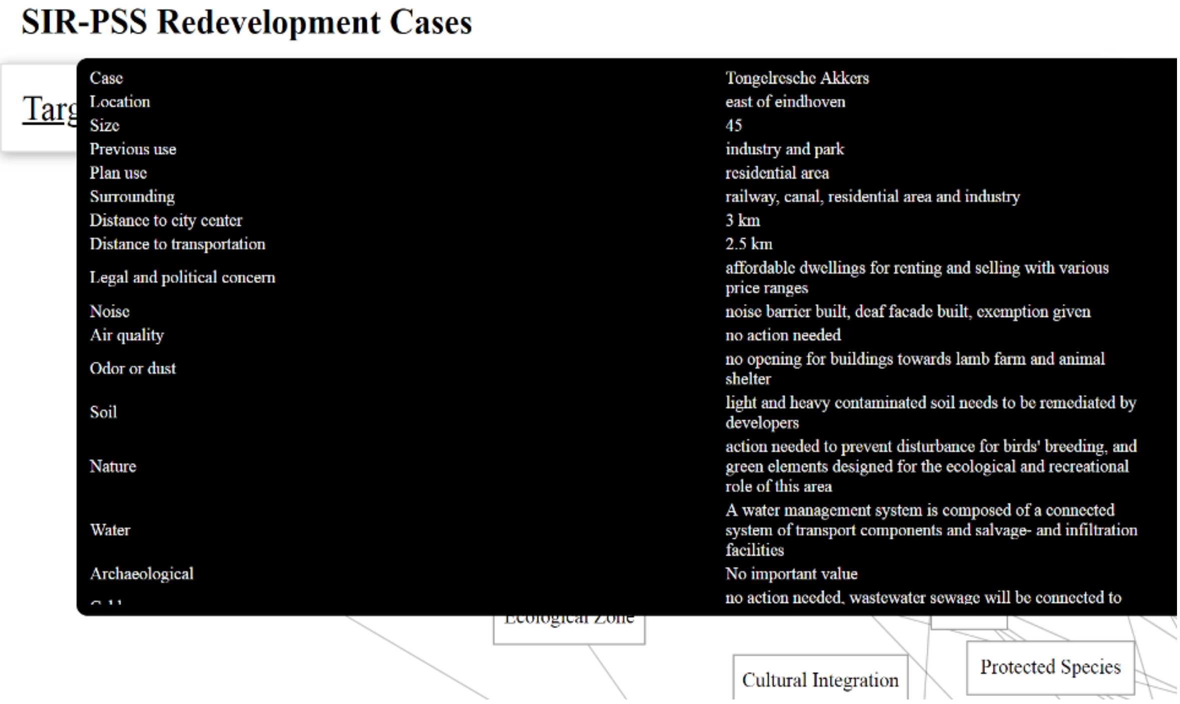

Figure 4.4.5. Complete case description on the web application

Detailed information summary retrieved from the web tool for these two cases are listed in Appendix C. The situation for the target site is also listed below in Table 4.4.1. Planners can use this information to compare the current case with past experience and design future uses. Scenario design is already listed in the planned use and expected outcome sections.

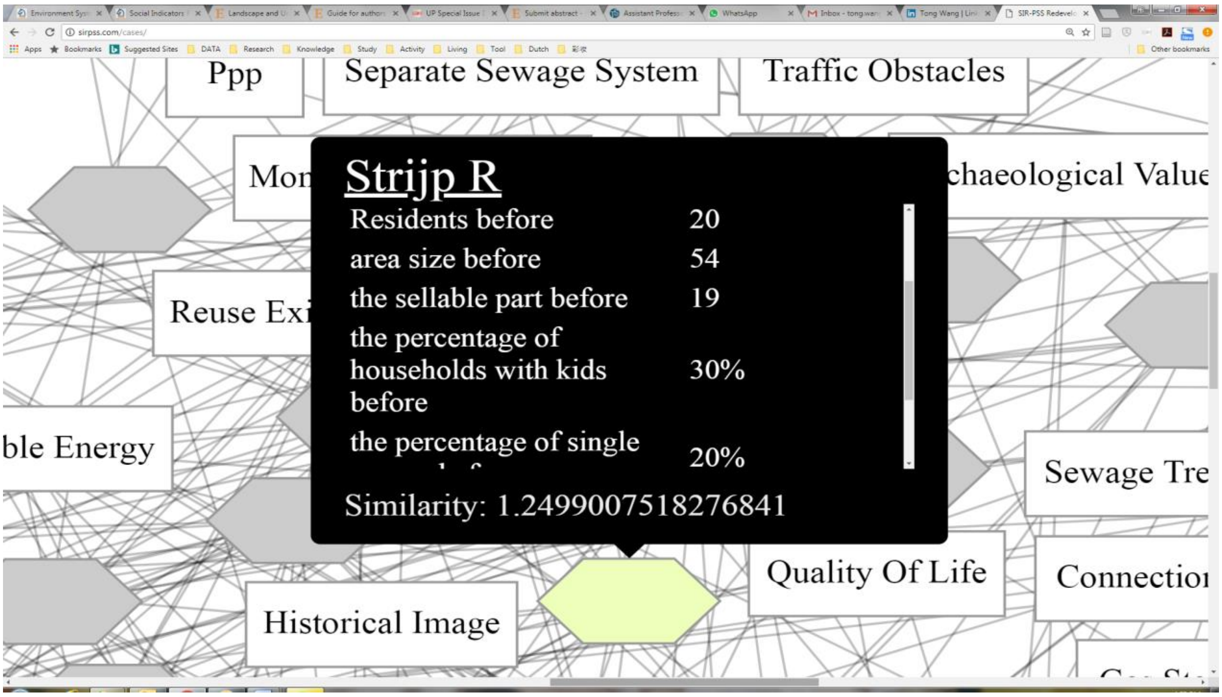

Figure 4.4.6. Simplified case representation tables on the web application

Table 4.4.1. Target site detailed information including design

Case	Target site
Location	North of Bergen op Zoom, the centre of Halsteren
Size (hectares)	24.6
Previous use (hectares, SBI in 1993)	Manufacture of concrete products for construction (0.45, 23611);Manufacture of motorcycles (0.07, 6420); Renting of other consumer goods (0.02, 77299);Shops selling water sports goods (0.02 ,47642);Taxi operation (0.07,4932);sale and repair of passenger cars and light motor vehicles (0.07,45112);Notaries (0.02,69103); Social clubs (0.07,94991);Petrol stations (0.04,4730);Wholesale of computers, peripheral equipment and software (0.035,4651);Wholesale of heating and cooling equipment (0.06,46692);Sale and repair of passenger cars and light motor vehicles (0.02, 45112);Mortgage, credit and currency brokers, bank and savings bank agencies(0.02, 66193)
Plan use	**Mixed use, Manufacture of concrete production for construction is changed into the manufacture of motorcycles; Public facilities such as green areas, supermarkets are added, so as the residential areas in the east-south.**
Surrounding	Near a bus stop (on the west), 1.5km to train station in the south, industrial area (north) with houses and green area (west)
Distance to city centre	4.3 km to centre of Bergen op zoom, 1 km to the centre of Halsteren
Distance to transportation	Next to bus stops and industrial area Wouwseweg
Political concern	Reuse existing buildings, Smooth transition
Noise	Near industrial area, noise should be reduced for industry remain because it is located near large residential areas
Air quality	Near industrial area, air quality should be monitored for industry remain because it is located near large residential areas
Odour or dust	Near industrial area, odour or dust should be reduced for industry remain because it is located near large residential areas
Soil	Needs to be cleaned for the concrete factory, which is building number 1 (SBI 23611)
Nature	Transition zones between the west and site for nature protection
Public transport	More bus lines
Expected outcome	**Houses and working with some light industry; South with the residential area, north industry; west office and commercial use**

For new redevelopment cases that focus on a particular vision, they can consult the past experience, as presented in this service. More concrete information beside the calculated attribute values can also be consulted from the related zoning documents. Users can also adapt the weights for the attributes that have been identified, and similar cases are automatically updated to form a new list based on the equation that has been presented. Further information can be retrieved from the database that has been created, such as other attribute values that are not directly visible in the web application, such as detailed zoning plan decision-making process, financial details and so forth. The proposed web-based tool can support locals and policymakers to discuss their plans before they make actual strategic decisions. Detailed scenario designs are implemented in ArcMap and CommunityViz for site level indicator calculation. We have constructed a mixed-use area where on the southeast it is transformed into housing since the southern area of the site is mainly residential land. North of the site is maintained to be industrial area since the northern side stays as big industrial park. To the west side, there is a green area, so the west side of the site is transformed into public facilities to facilitate the new site and also provide a smooth transition between the site and the surrounding green area. The scenario is called a base scenario and is presented in Figure 4.4.7.

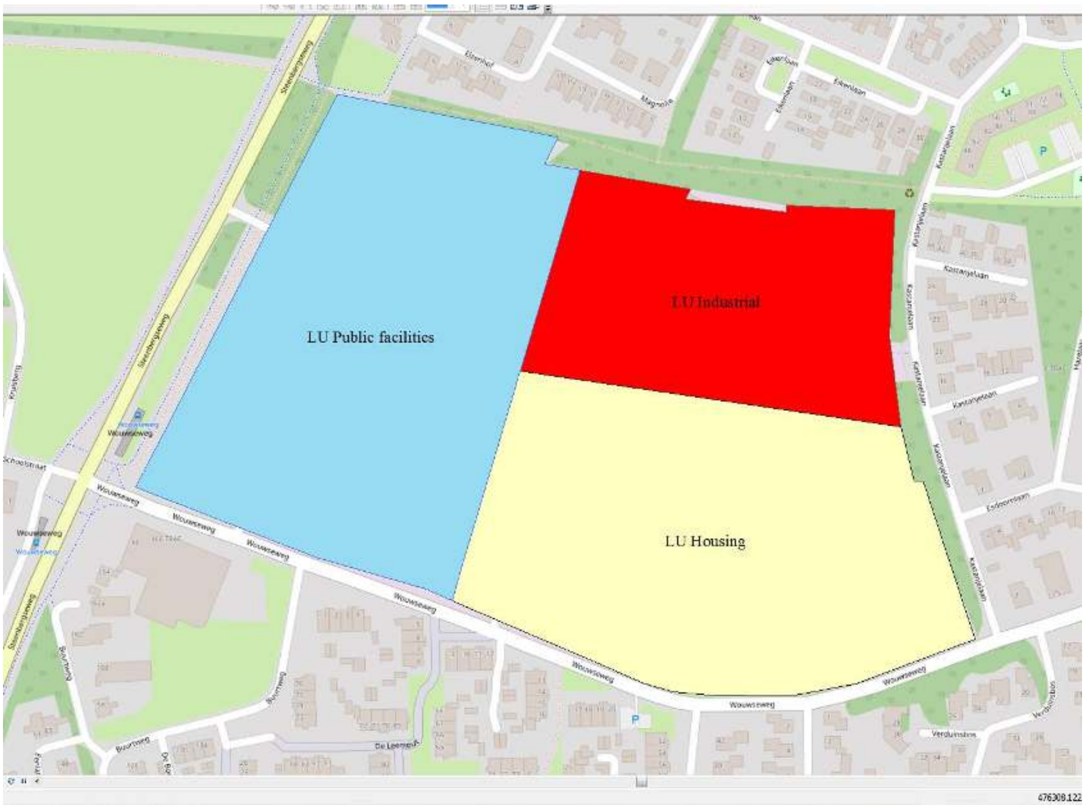

Figure 4.4.7. Scenario for the target site design

To incorporate this new design into the regional sustainability analysis, this scenario is imported as a zoning plan into land use change simulation models so that future land use situation can be simulated. An original scenario which does not change land use function is also imported into land use simulation model to compare with the new design. This non-changed scenario is referred to as an original scenario. Regional sustainability indicators regarding physical conditions can be therefore predicted based on a calculation of physical indicator related attribute values. For site level sustainability evaluation, the past experience is analyzed, and their normalized outcome (based on site area) is projected onto the new redeveloped case.

4.5 Land use transition analysis [9]and simulation[10]

The results of the case study with the focus on industrial land use are presented from section 4.5.1 to 4.5.5. Table 4.5 shows the land use types that are actively modelled in the illustration application. Land use types are categorized into three groups: features are the land use types which do not change during the simulation (not shown in Table 4.5); vacant lands only change into other land uses; and functional lands are actively modelled, like residential or industry. Functional lands change dynamically as the result of the local and regional dynamics (van Vliet et al., 2013) and many detailed land use functions are accumulated into a single code for simplicity. Line-alike features like roads, rivers, and other water areas are not considered since they cause problems for the calculation of surrounding percentages. These line-alike features take most of the ratio in a buffer zone of industrial sites while other land uses cannot easily be detected. These features can be added later in land use change models by inserting accessibility maps and hydrological network maps. Besides, they are less likely to change during the simulation period (12 years).

Since this research focuses on the redevelopment of industrial sites, a detailed analysis of the industrial site redevelopment process is also presented beside the land use model construction process. These results are further integrated into a new case design process. It is easier to

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[9] Modified based on Wang.T, Han,Q.,de Vries, B., (2019). Industrial Site Redevelopment Process Analysis. *European Planning Studies (submitted).*

[10] Modified based on Wang, T., Han, Q. & de Vries, B. (2017), A semi-automatic neighborhood rule discovery approach, Applied Geography, Vol 88, pp 73-83, ISSN 0143-6228, DOI: 10.1016/j.apgeog.2017.08.014

understand the regional characteristics once the redevelopment process has been analyzed. This process also guides the calculation of physical related sustainability indicators.

Table 4.5. Land use code illustrations

Land use code	Land use type	Group
0	Agriculture	Vacant
1	Housing	Function
2	Retail	Function
3	Public facilities	Function
4	Social-cultural facilities	Function
5	Industry	Function
6	Recreation	Function

4.5.1 Land use inertia

In this step, the tendency of land use to stay the same, its inertia, is analyzed. Metrics for land-use maps from 2000 and 2012 are compared in a contingency table. This is a matrix that shows how much one land use has changed into another, for all combinations of land use. Table 4.5.1 gives an illustration of how such tables look. Public facilities include municipal facilities, police stations, and prisons. Social-cultural facilities are used for museums, universities and conference centers. (Centraal Bureau voor de Statistiek, 2003). Note that we have used cell numbers since we have deleted features with sizes less than 10,000 m^2 in the detection of land-use transitions, but these features are also crucial for inertia evaluation. For example, 87% of industrial land remained unchanged from 2000 to 2012 (2000: 10752 cells; 2012: 9351 cells), equivalent to a rate of 0.87. While for retail land, the rate unchanged is 0.74 (2000: 773 cells; 2012: 573 cells). If the industrial land's inertia is scaled to 100 in the land-use model, retail land's inertia will take on a value 100*(0.74/0.87), or approximately 85. This can be explained by the fact that industrial sites are more challenging to change considering the complicated redevelopment process, compared to retail land. The inertia of other land uses is analyzed in the same way.

Table 4.5.1. Land use contingency table

	Housing	Retail	Public facilities	Social-cultural facilities	Industry	Recreation	Total (2000)	Unchanged rate
Housing	**19048**	354	7	137	211	640	**21853**	**0.87**
Retail	78	**573**	3	14	41	9	**773**	**0.74**
Public facilities	42	38	**1362**	81	82	36	**2062**	**0.66**
Social-cultural facilities	148	62	9	**1650**	59	70	**2235**	**0.74**
Industry	99	120	45	31	**9351**	176	**10752**	**0.87**
Recreation	436	22	19	90	129	**12917**	**14898**	**0.87**
Total (2012)	22316	1431	1908	2227	13238	17055	510487	

4.5.2 Surrounding land use influences on industrial sites to appear and the impacts

This process identifies surroundings that trigger industrial sites to appear and studies the impact that these new industrial sites have on the surroundings. Planners can use such evidence to select a potential industrial site for development and evaluate the impact on surrounding land of such a development. One example of this type of analysis is shown in Figure 4.5.2.1. The left-hand image shows which surroundings tend to trigger a change from agricultural land use to industrial land use. The “After-Agriculture-to-Industry” image on the right shows the neighborhood composition after transition. The x-axis represents the distance from the new industrial sites to other land uses (LU), and the Y-axis represents the relative presence of surrounding LU. This is calculated based on equation (3.5.9). A positive value means that one land-use type’s percentage near new industrial sites is higher than its overall regional distribution, and vice versa.

From the left side of Figure 4.5.2.1, within 100 meters to 800 meters radius (X-axis), the relative presence of agriculture and industry are both positive, while the relative presence of other land-use types is negative. This shows that agricultural areas that change to industrial are surrounded by more than average amounts of industry and agriculture, but less than the average amount of other land-use types.

Comparing the left and right side of Figure 4.5.2.1, the relative presence of retail land is increased tremendously (green line) at all distances from new industry and that of industrial land increases within 300 m, as does recreational land. However, the relative presence of social-cultural facilities decreases within 100 and 500 meters. The proposed process can be used as an evaluation procedure for land use development plans.

Planners can compare the change in relative presence of each land use type near newly appeared industrial sites more thoroughly by splitting the image into each land use type. However, the emphasis of this research is to illustrate, and analyze, the process of industrial site redevelopment, so land use types near new industrial sites are not split here.

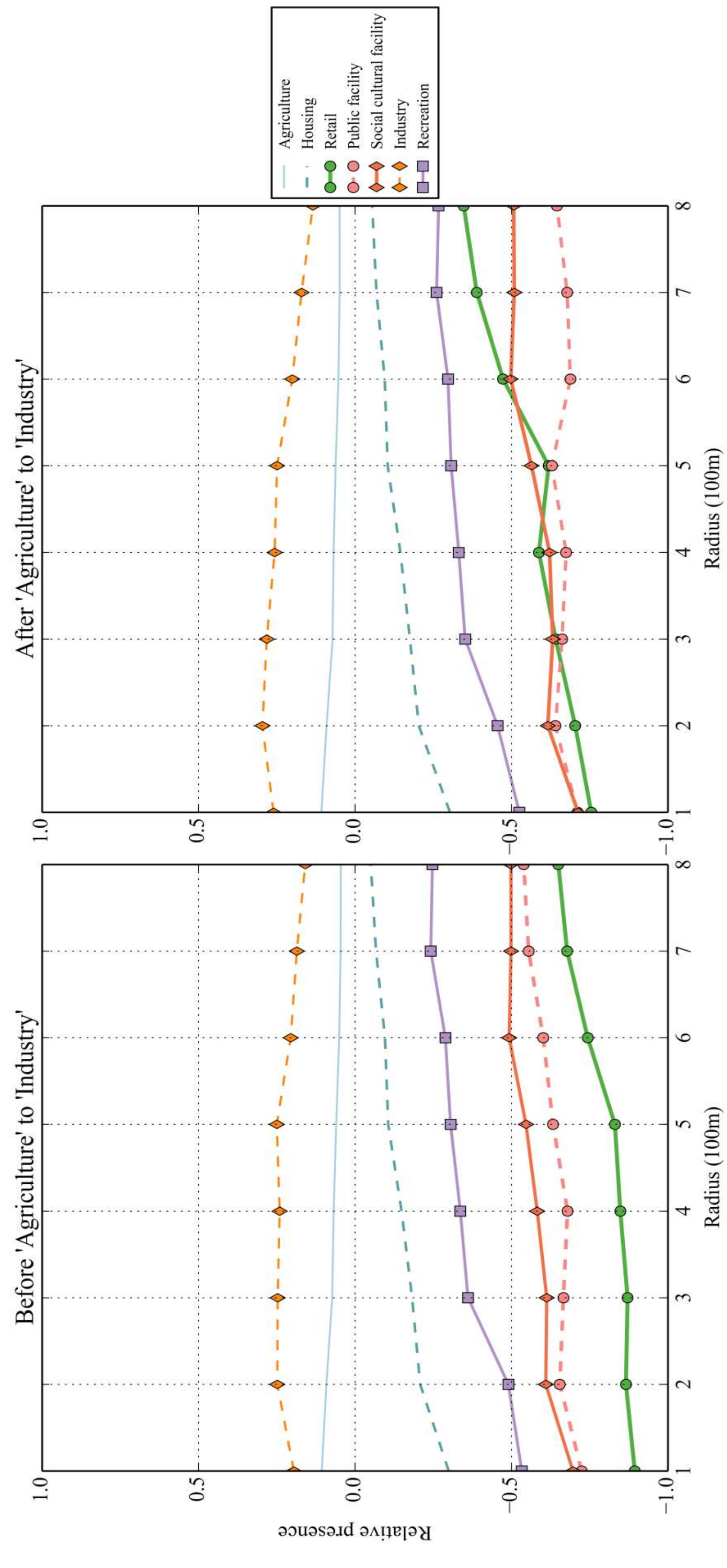


Figure 4.5.2.1. Surrounding land use influences for agricultural land to become industrial sites and the impacts of such transition

In the proposed model, the influence of other land uses on planned industrial land at distance zero is calculated by comparing the changed rate of these land uses to industrial land with the unchanged industrial land rate. In the benchmark model, the unchanged rate of industrial land is modeled as a value of 100. Considering such a pair of land uses {A, B}, the value for B's influence on A is then calculated as (Percentage of B changed into A)*100 / (percentage of industrial land not changed). For other distances, the influences are calculated from images generated of neighborhood land use. Figure 4.5.2.2 presents the relative presence of land uses in the neighborhood before industry appears and is used to determine neighborhood rules that signify other impacts of land use on industry. At 100 m, the relative presence of industrial land is 0.7, which is modeled in Metronamica as a value of 1. Thus, the influences of other land use on industrial land are calculated as "the value for distance 100 m" / 0.7. The influences of other land use on industrial land beyond 200 meters away are modeled as zero for simplicity. Further research can explore bigger influential areas, using a similar method.

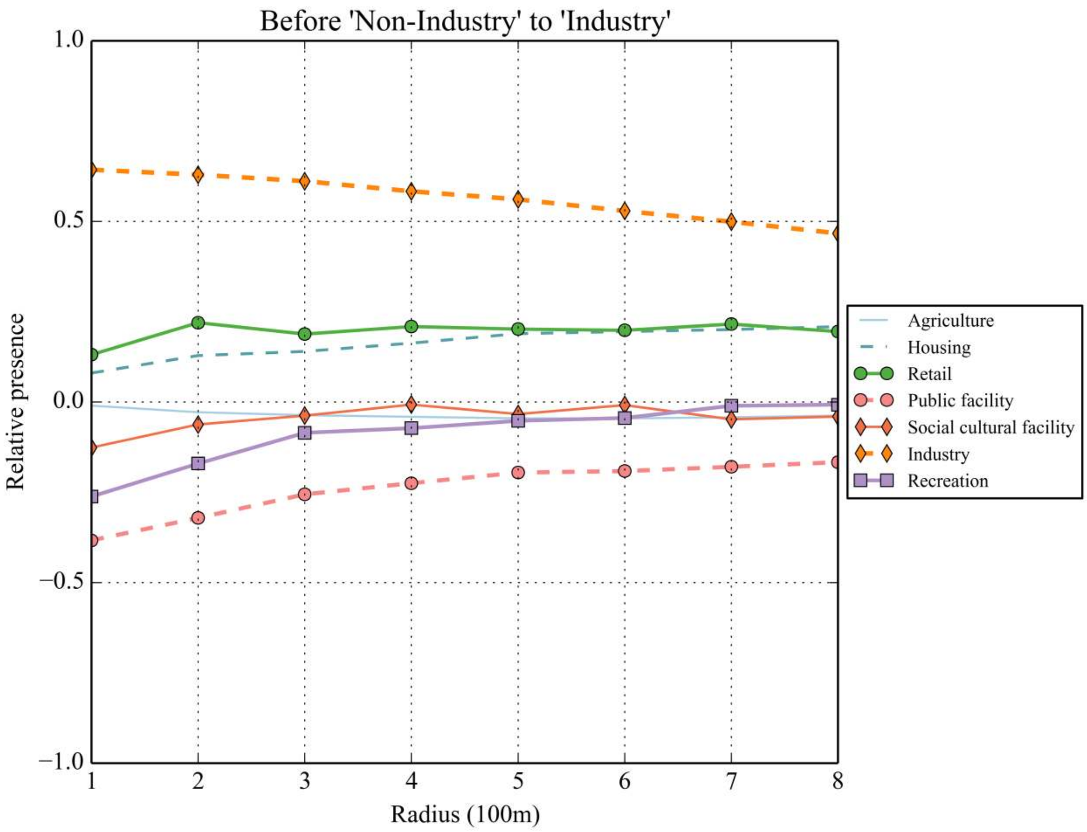


Figure 4.5.2.2. Generated image of land use relative presence for areas changed into industry

4.5.3 Regional industrial site redevelopment characteristics

Table 4.5.3 provides information on how industrial sites are transformed in this region. This is based on the cadaster data from the first two years period. In our case study, this is from the year 2000 and the year 2008.

Table 4.5.3 can be used as a reference for scenario designs in case of further redevelopments in the region. The unique code generated in 3.5 for each industrial feature in the dataset is used to calculate industrial site transition frequencies. From this frequency table, industrial sites in North Brabant are mostly transformed into housing and retail. If a target site needs to be redeveloped later, it might be redeveloped into housing or retail as well. One of the reasons is that there are many expats and students living in major cities like Eindhoven and Tilburg. Local universities and big companies attract many people to move to the region. As a result, more accommodation is needed to meet the new market demands. Retail places are also necessary for these people. Other regions might have a different transition frequency table. This is regional context specific.

Table 4.5.3. North Brabant region industry transition frequency table based on features left (areas > 10,000 square meters)

Redevelopment use	Frequency	Percentage
Housing	31	30%
Retail	47	45%
Public facilities	10	10%
Social-cultural facilities	8	7.5%
Recreation	8	7.5%
Sum	104	100%

4.5.4 Surrounding land use influences on industrial sites to disappear and the impacts

This process aims to find what causes industrial sites to be transformed and the impacts of the transition on the surroundings. Generated images show changes in the relative presence of each land use type, both before and after an industrial site is transformed. The example in Figure 4.5.4.1 shows all the surrounding land use types near disappeared industrial sites and the impacts on the surroundings of transitions from industrial to retail. According to the left side of Figure 4.5.4.1, before industrial sites are transformed into retail, the relative presence of retail, industry, housing, and social-cultural facilities are all positive, which means that their percentages are all higher than their overall regional distribution. It is therefore concluded that industrial sites with much retail, industry, housing and social-cultural facilities nearby, are easier to transform into retail. Comparing the left and right sides of Figure 4.5.4.1, users can see that after such transitions, social-cultural facilities are reduced within 700 meters (pink diamond on solid line), and public facilities (pink circles on dashed line) are much more reduced in the surrounding from 100 to 800 meters. Other transition possibilities can be analyzed in the same way. The detailed conclusion is presented later.

In Figure 4.5.4.1, all the land use types are included in an image. To analyze each transition more clearly, it is possible to show images for each specific land use type that address the differences before and after a specific transition form (such as an industrial transition), for each land use type in the surroundings. There are in total five observed transition forms in the North Brabant region. Table 4.5.3 and 4.5.5 present the transition frequency for the whole region and urban and non-urban areas respectively. This demonstrates the range of influence of each industrial site transition on surrounding land uses. From all the images that are generated, the most obvious changes to the relative presence of surrounding lands are listed in the following paragraphs. These images are based on every industrial site transition form in Table 4.5.3.

Figure 4.5.4.2 shows that the relative presence of recreational land is increased from 100 to 200 meters after industrial sites are transformed into housing. In other words, industrial sites have a negative influence on recreation, compared with housing's influence on recreation in this range. Beyond 200 m, there is less recreational land after the transition than before. This can be explained by the fact that new housing projects typically contain relatively small recreational areas nearby, so further recreational sites are not that necessary anymore.

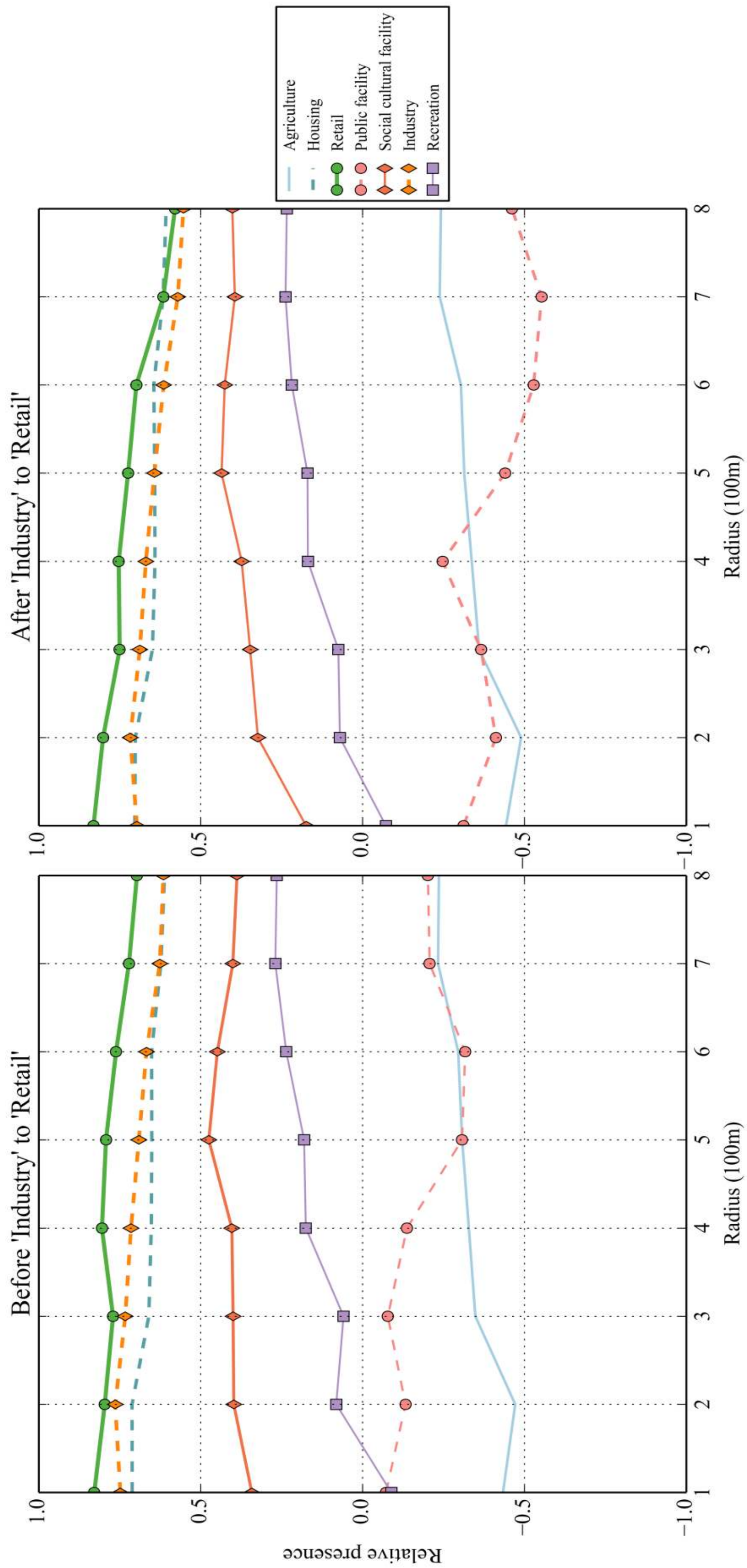


Figure 4.5.4.1. Surrounding land use influences for industrial sites to become retail and the impacts of such transition

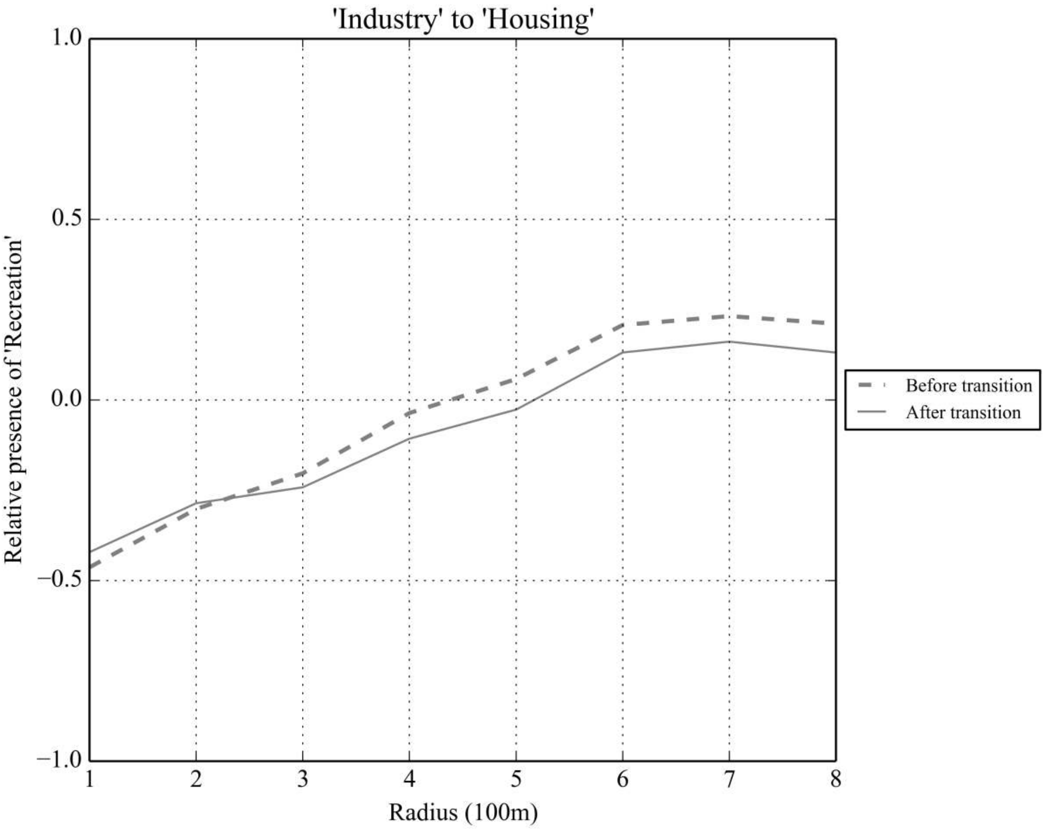


Figure 4.5.4.2. Relative presence changes in the surroundings of industrial sites changed into housing

As explained in Figure 4.5.4.1, public and social-cultural facilities are reduced after industrial sites are transformed into retail. Figure 4.5.4.3 shows a more unobstructed view of what the influential ranges are. The existence of industrial sites has a more positive impact than retail on social-cultural lands within 700 meters and on public facilities till 800 meters. After all, large industrial sites require public facilities and social-cultural facilities nearby. While for retail areas such as department stores, these facilities are not commonly accommodated.

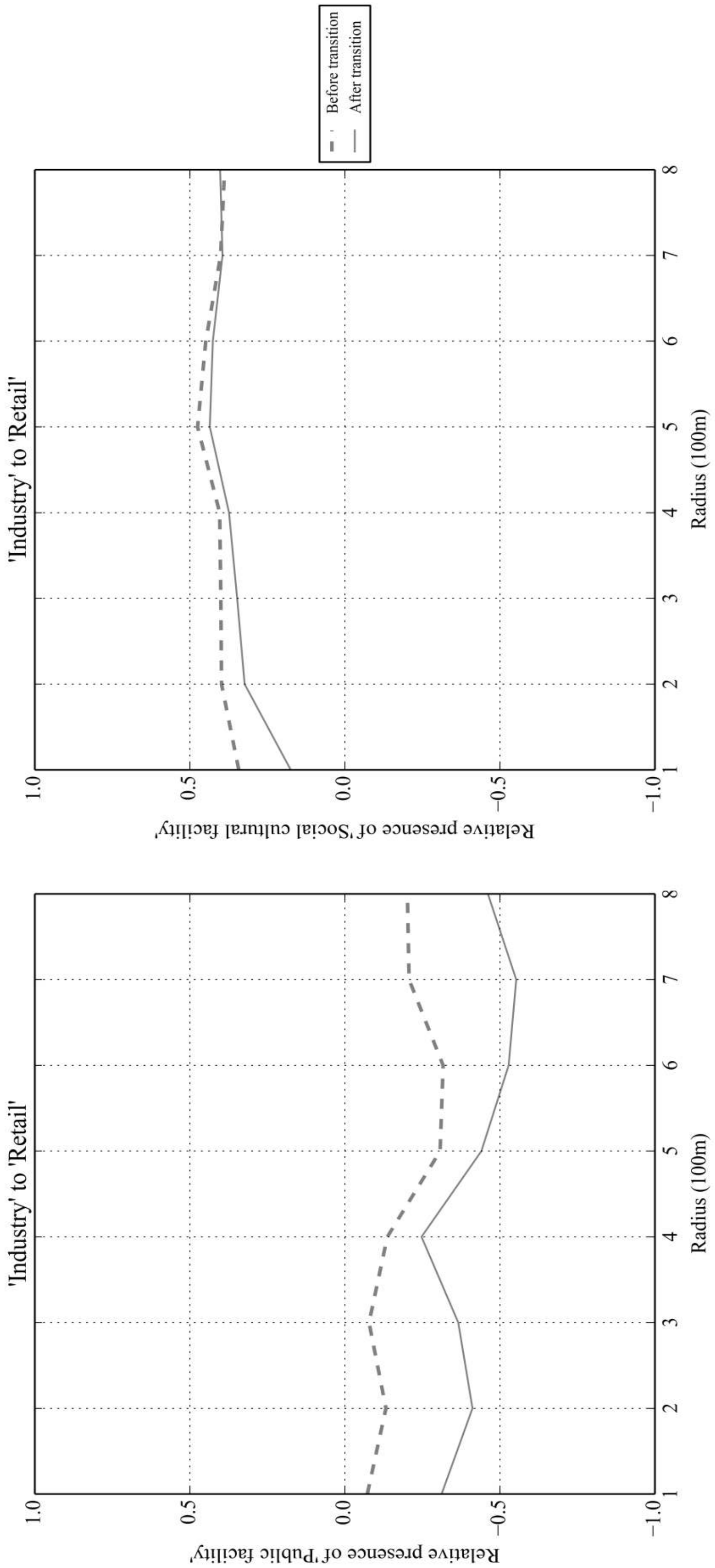


Figure 4.5.4.3. Relative presence changes in the surroundings of industrial sites changed into retail

Compared with public facilities, industrial sites have a more positive impact on retail at all scales since the relative presence of retail decreases after industrial sites transform into public facilities. However, industrial sites have adverse effects on social-cultural facilities within 100 to 600 meters, as shown in Figure 4.5.4.4. These retail sites are often building-material shops or big supermarkets close to the industrial sites which are ordinarily logistic centres. It is convenient for these shops to transport goods. After the transition, there are no longer any nearby public facilities since they cannot get their supply from industrial sites as easily as before. However, more social-cultural facilities come near public facilities to accommodate the new function.

According to Figure 4.5.4.5, the relative presence of recreational land is reduced within 500 meters range where industrial sites are transformed into social-cultural facilities. Retail is also reduced, with a longer range till 800 meters. In other words, the existence of industry has a positive impact on retail and recreation compared with the existence of social-cultural facilities. This could be explained by the fact that industrial sites require more transition zones such as recreational lands for environmental concerns.

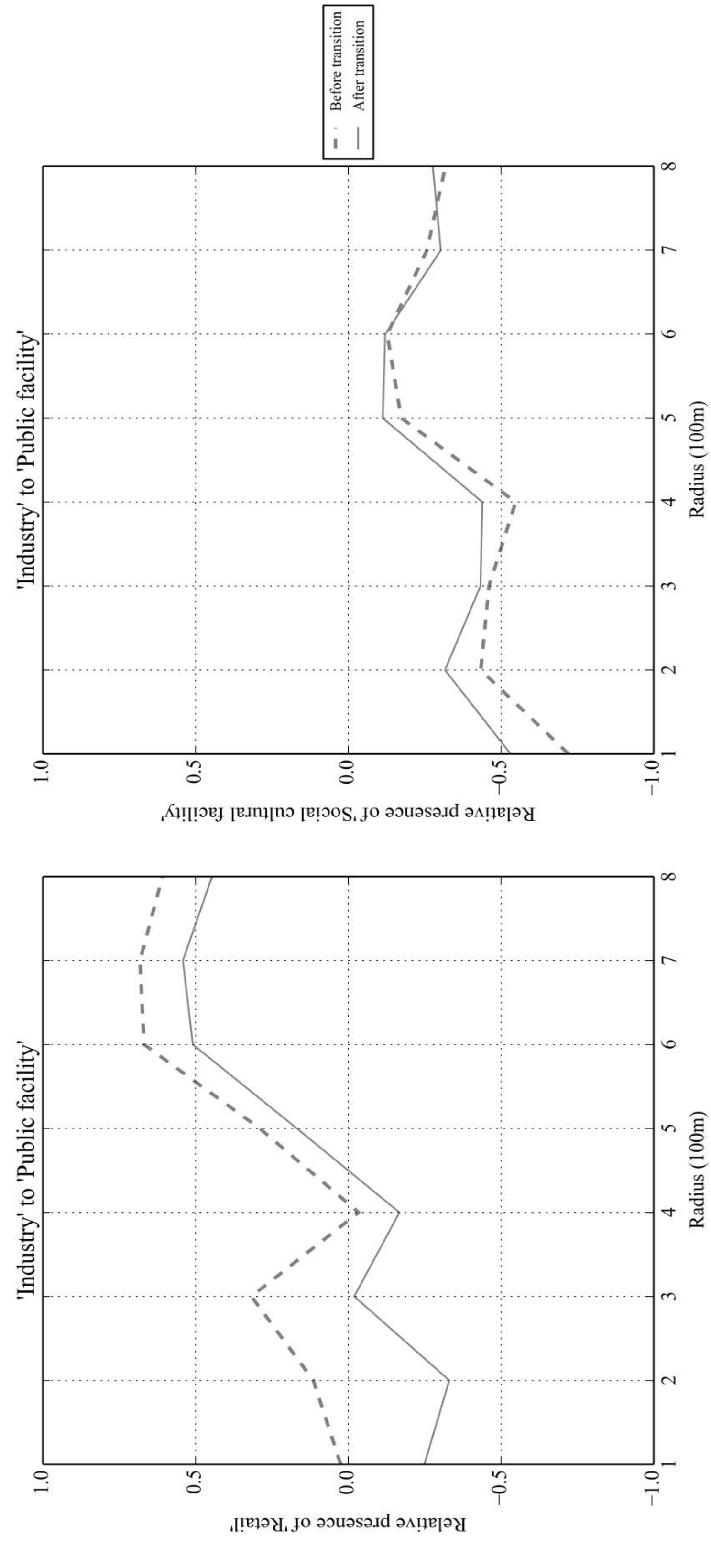


Figure 4.5.4.4. Relative presence changes in the surroundings of industrial sites changed into public facilities

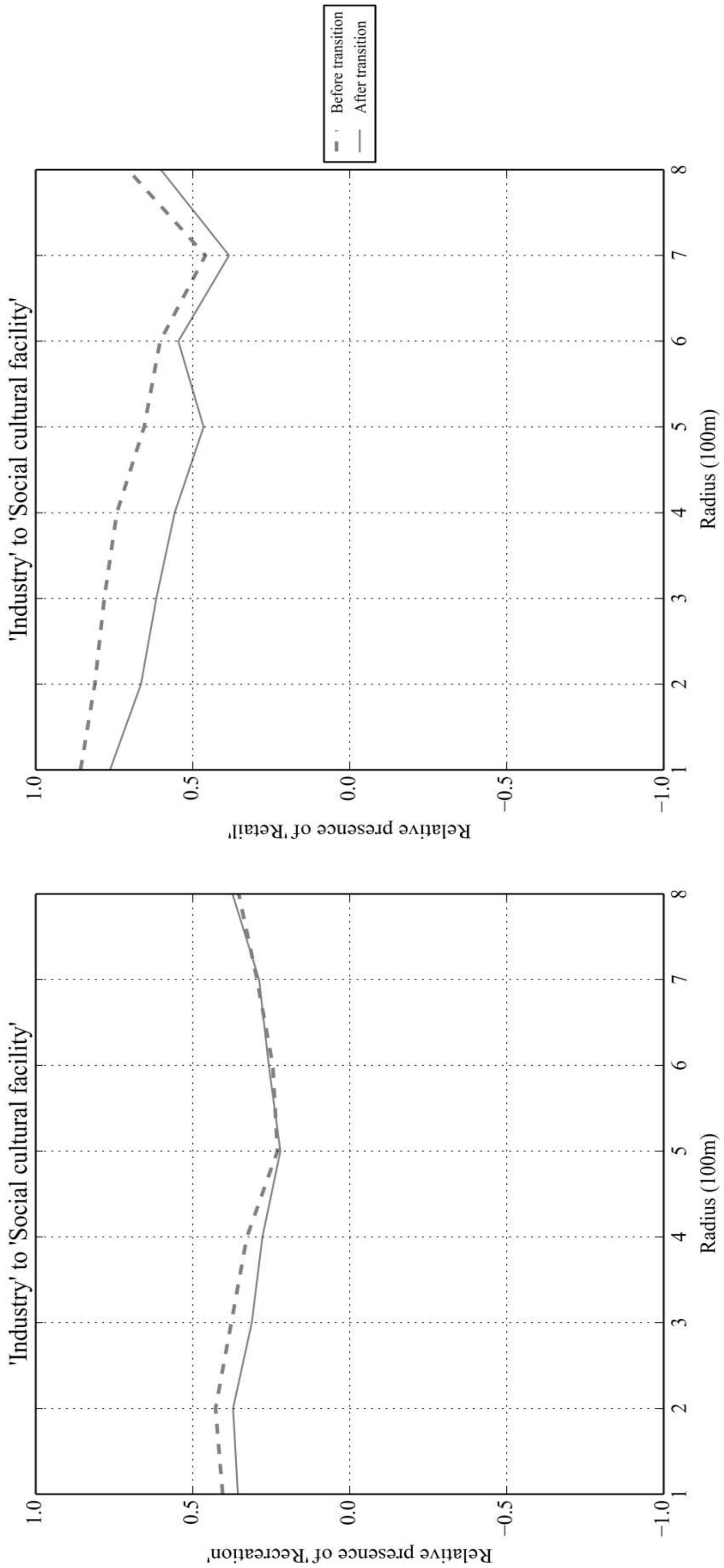


Figure 4.5.4.5. Relative presence changes in the surroundings of industrial sites changed into social-cultural facilities

Figure 4.5.4.6. shows that if industrial sites are changed into recreational land, more retail facilities start to appear between 300 meters and 500 meters. This also means, in reverse, that industrial land has a negative impact on retail at this distance. It is also clear from the image that there were no retail sites whatsoever in North Brabant at 400 meters distance of industrial sites before the transition. This could be explained by the fact that not many industrial and retail features are left for analysis. Within 300 meters, retail decreases after the industrial transition to recreational land. This shows the positive impacts of industrial sites on retail, compared with recreational land impacts on retail. These retail sites commonly represent large department stores which are generally near industrial sites.

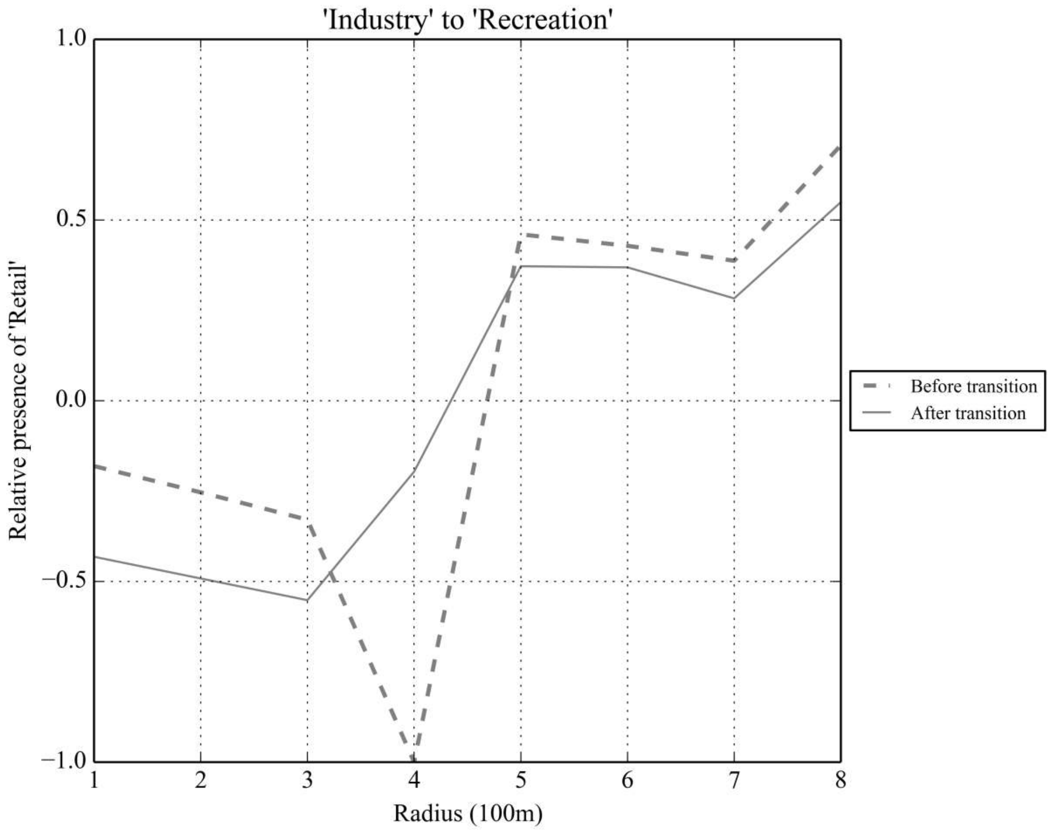


Figure 4.5.4.6. Retail relative presence changes after industry transformed into recreational lands

Up until now, the influence of industry on other land uses is found by comparing with each specific land use type. For example, in comparison with public facilities, industrial sites have positive effects on retail but adverse effects on social-cultural facilities. However, the previously shown images only visualize the relative presence of one land use type surrounding specific industrial transitions. It is still difficult to determine whether the influence of industry as a whole should be positive or negative on other land uses. Therefore, we have compared the relative presence of all types of land use around industrial sites before and after the industrial site change, no matter which transition the industrial sites undergo. If the percentage of one land use type is increased after the transition, then industrial land must have had a negative impact on this land use type before the transition.

The aggregate difference of relative presence for all land use types after and before the industrial land transition is shown in Figure 4.5.4.7. Positive values show increased relative presence after industry transition, and vice versa. And increased relative presence reveals the negative influence of industrial sites on this specific land use.

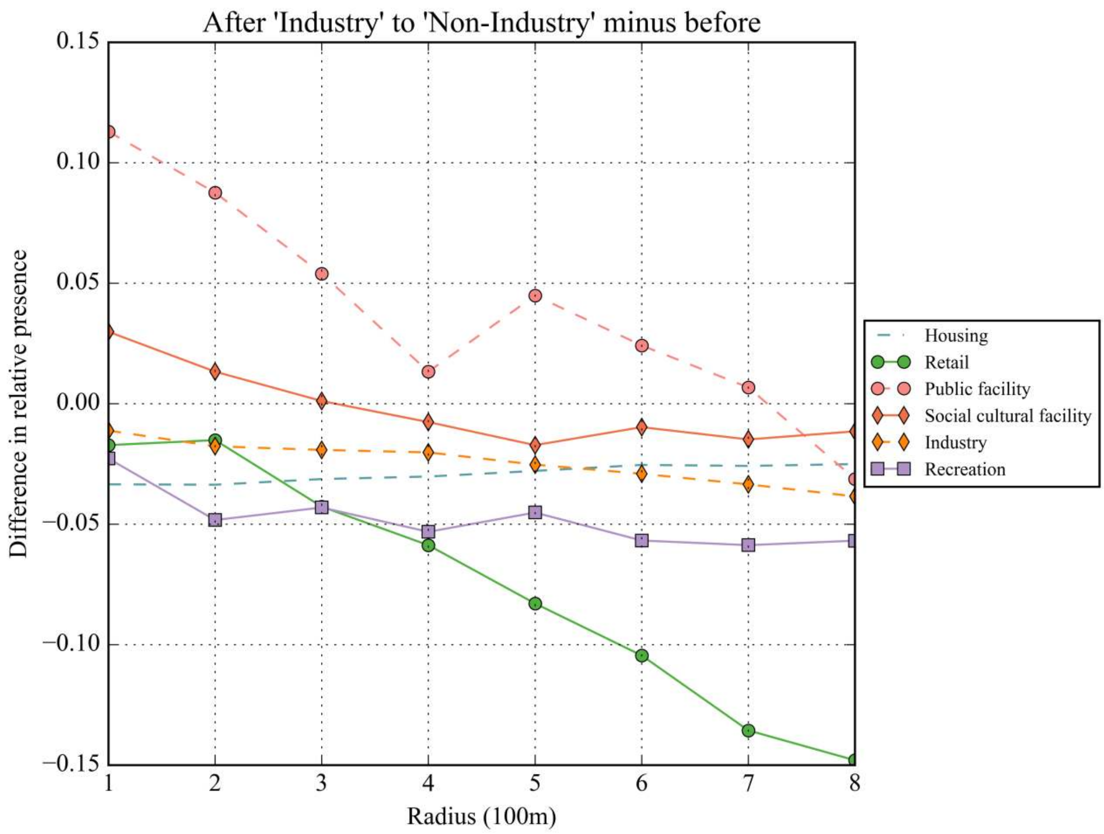


Figure 4.5.4.7. The difference in relative presence after the industrial land transition

According to Figure 4.5.4.7, the following observations can be made: Industrial sites have adverse effects on public facilities (pink circles dashed line) from 100 to 700 meters and social-cultural facilities (orange diamonds solid line) in the 100-200 meters neighbourhood while an adverse effect on retail, recreation, and housing within 800 meters. The positive influences of industry on these land uses could be explained by the fact that the North Brabant region is focusing on industrial redevelopment and many facilities and accommodations are needed to meet the increasing demands on the market. Local governments are trying to redevelop industrial sites to bring more economic activities and satisfy the current needs. Therefore, many industrial sites are being transformed into other uses.

The Python® script developed for the analysis automatically generates images which show the difference in relative presence for each land use type near an industrial site before and after its transitions. Figure 4.5.4.2 shows that changing industrial sites into housing attracted more recreation facilities to the neighborhood.

These images show the influence of industrial sites on other land uses by pair-wise comparisons of each specific land use type. However, it is still difficult to determine whether the influence of industrial land as a whole should be positive or negative on other land uses. Thus, the change in relative presence of all land uses surrounding an industrial site is calculated, no matter which transition the industrial site takes. If the percentage of one land use type is increased after the transition, then the industrial land has had a negative effect on this land use type.

Figure 4.5.4.7 is also used for deriving neighborhood rules for the impact of industrial land on other land uses. The influence for 100 meters distance is calculated based on "the value for 100 meters distance" / (-0.02) where -0.02 is the value of the industrial land itself, the relative presence difference of industrial land after and before the transition in the 100 meters neighborhood. For 200 meters, all the influence values are set to zero. To model land-use inertia at distance 0, we have used the unchanged rate of the target land use instead of unchanged industrial land rate.

4.5.5 Urban & non-urban comparison

The whole of North Brabant is split into urban and non-urban areas. As a result, differences between urban, and non-urban, industrial land transition can also be analyzed and it shows the robustness of the proposed approach. A frequency table is provided in Table 4.5.5.

In urban areas, industrial sites are mainly transformed into retail, housing, recreation and social-cultural facilities, while in non-urban areas; industrial sites are mostly redeveloped into retail, housing and public facilities. There are more industrial sites transformed in non-urban areas. This can be explained by the fact that recently more North Brabant housing projects have been allocated to non-urban areas because the permit acquisition process is simpler. To facilitate these housing projects, retail and public facilities must also be built. Since non-urban areas guarantee access to open spaces (treated by users as the equivalent of green spaces), little recreational space is created. However, in the urban areas, more recreation is needed for sustainable requirements.

Table 4.5.5. Urban and non-urban industry transition frequency table based on features left (areas > 10,000 square meters)

Redevelopment use	**Frequency in urban areas**	**The percentage in urban areas**	**Frequency in non-urban areas**	**The percentage in non-urban areas**
Housing	9	22.5%	22	34.5%
Retail	18	45%	29	45%
Public facilities	2	5%	8	12.5%
Social-cultural facilities	5	12.5%	3	5%
Recreation	6	15%	2	3%
Sum	40	100%	64	100%

4.5.6 Land use model calibration

Adaptations were made to the benchmark model of Metronamica by adjusting the rules derived from the vector data. This saves time by providing the most important neighborhood rules, compared to starting from scratch. As mentioned in the literature review, the most common way to calibrate a CA land use change simulation model, and to check the rule settings, is to compare the simulated land use maps with the actual maps from the same year using statistics. Statistics such as Kappa, Kappa simulation, and Fuzzy Kappa simulation can be used. Kappa only measures the agreement between two categorical maps, corrected for expected agreement. Kappa simulation references the initial land use map by comparing the amount of change for each land use across the whole region. Fuzzy Kappa simulation combines both initial map and geographical fuzziness for distinguishing small and large discrepancies in position and land use classes. Calibration results are listed in Table 4.5.6. From the table, we can see that our approach (which applies original feature shapes and uses derived visualized rules from historical data) can improve the performance of the simulation, especially for Kappa simulation and Fuzzy Kappa simulation results. The proposed approach can be used to improve land use change modelling results. Although we have applied the derived neighborhood rules from vector maps to raster-based land use change models, the discovery process is generic and can be applied to vector land use change models as well. Our approach can be used as a plugin into the existing raster models or vector models with the advantage of setting rules effectively and efficiently. Currently, it is only applied to the raster-based model environment.

Table 4.5.6. Land use model calibration results (best value 1)

Comparison algorithm	Benchmark	Our model
Kappa	0.8837	0.8839
Kappa simulation	0.0283	0.0324
Fuzzy kappa simulation	0.0339	0.0369

Figure 4.5.6 presents the actual and simulated land use cover in the year 2012 for the North Brabant region. Visual interpretation and judgement are applied to check the similarities between these two maps. As have been tested, the current land use model provides a reasonable, realistic land use outcome, compared with the historical data. Currently, only the most important industrial land use change neighbourhood rules are implemented in the land use simulation model. These rules include industrial land and other land use types interactions within distance 200 meters. They are selected based on images visual interpretation. All the images are generated based on the same scale so that the most significant changes can be identified upon a glance. It is worth noting that limited changes have been made to the benchmark model, regarding Kappa simulation and Fuzzy Kappa simulation results, while these derived rules already have improved the calibration results. Further improvements can be made by using the proposed procedure for other land use type's interactions.

4.5.7 Robustness of the methodology

To study the robustness of the proposed approach, the whole region has been split into urban and non-urban areas. The same procedures of calculating and setting up neighborhood rules in Metronamica have been performed on urban and non-urban areas respectively. To be more specific, for both urban and non-urban areas, similar images showing the relative presence of nearby land use types are generated, and neighborhood rules applied between industrial land and other land use types within 200 meters are applied.

Table 4.5.7 presents the calibration results of our land use models for urban and non-urban areas, compared with the benchmark models. The two proposed models of land use change perform better than the benchmark model, especially for Kappa simulation and Fuzzy Kappa simulation results. Because of the semi-automatic procedures, the time for setting up land use change models is reduced because no iterative adjustment is needed. No expert knowledge is needed, and the images give a clear starting point to set the most important neighborhood rules.

Table 4.5.7. Model calibration for urban and non-urban areas

Comparison algorithm	Urban benchmark	Urban model	Non-urban benchmark	Non-urban model
Kappa	0.8251	0.8269	0.8921	0.8923
Kappa simulation	0.0211	0.0254	0.0244	0.0260
Fuzzy kappa simulation	0.0232	0.0274	0.0294	0.0301

4.5.8 Zoning map incorporation

Following section 4.3, the chosen site was designed for redevelopment into housing, public facilities, and industry. A raster map was therefore created for this site with these destination purposes and imported into the Metronamica zoning plan module. The priority of this plan is set to the highest level so that this area is forced to change to the target uses instead of other uses. Figure 4.5.8 shows the new zoning plan map based on the designed scenario. Actively simulated means that this site is actively transformed into the exact use stated in the design purpose, while restrict simulated means that this site is not actively transformed into that use. Indicators can be calculated using the dynamic change of the land use situation.

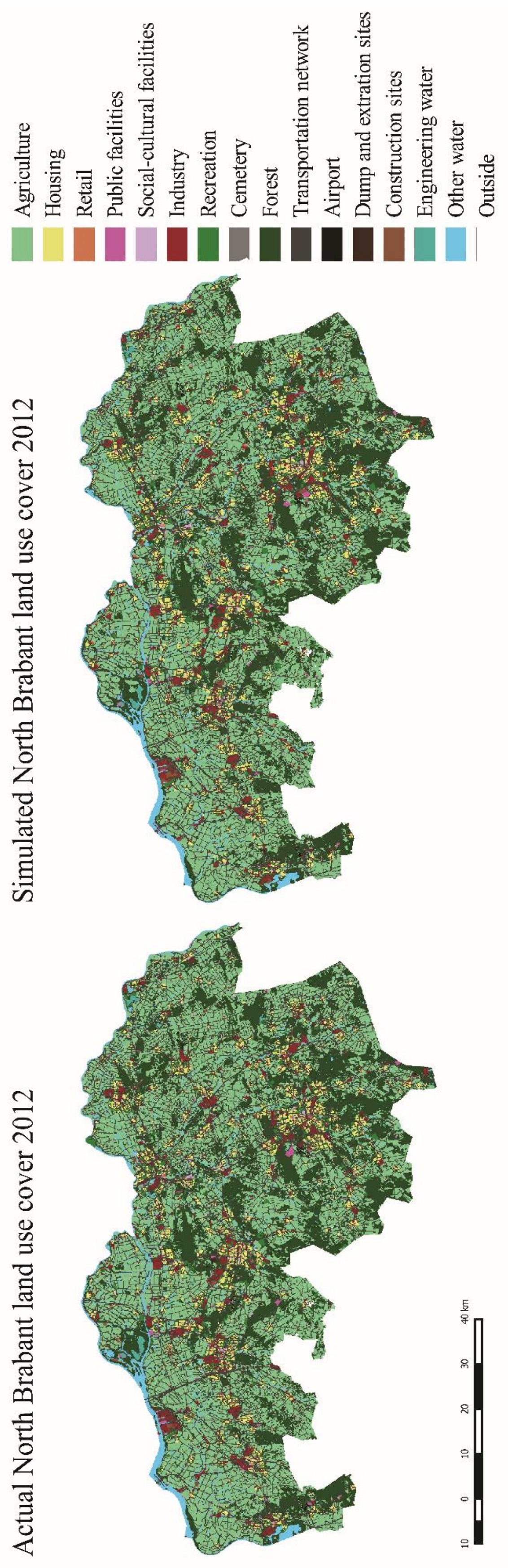


Figure 4.5.6. Actual and simulated land use maps of North Brabant region in the year 2012

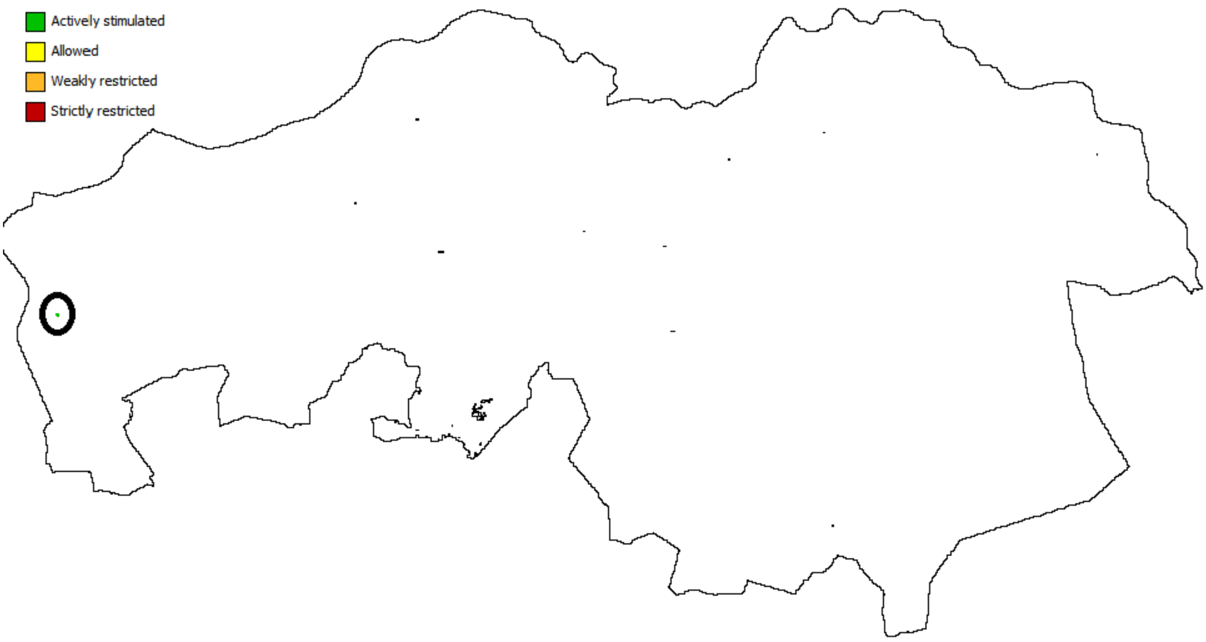


Figure 4.5.8. Zoning plan importation into land use simulation model

4.5.9 Land use transition and simulation summary

This section presents the calibrated land use change simulation module using case study area data. The regional industrial land transition is analyzed in detail.

To summarize the land use transition analysis results for the North Brabant region, industrial sites near a high concentration of retail, industry, housing, and social-cultural facilities but a lower concentration of other land uses are suitable for transitioning into retail and housing. The transition into retail causes less social-cultural (till 600 meters) and public facilities (till 800 meters) and the transition into housing attract more recreation (till 200 meters), social-cultural (till 300 meters) nearby but less retail and public-facilities from 100 meters further. Industrial sites are easier to transit into public-facilities if they are near more than the regional distribution of industry, retail, and housing, but less than the regional distribution of public, social-cultural facilities and recreation. And such transition from industry to public-facilities attracts more public-facilities (till 400 meters) and social-cultural facilities (till 500 meters), while reduces the amount of retail dramatically in the whole analysis range (800 meters). Industrial sites where all other land use types are more than regional distributions (except agricultural land) are more intended to transit into social-cultural facilities, and this causes less retail in the whole analysis range and less recreation till 500 meters but more public-facilities till 400 meters. Industrial sites near more than average housing, industry, and social-cultural facilities but less than average retail, recreation, and public facilities are more intended to become recreational land, and this causes more retail between 300 and 400 meters range and more recreational land within 300 meters, but less housing (till 500 meters) and less retail (till 200 meters).

This transition analysis supports planners in choosing redevelopment sites and evaluating their land use redevelopment proposals by showing the impacts of their proposed strategies on the surrounding land uses. If planners want to redevelop an industrial site into a retail site, they need to check which surrounding compositions are more suitable in order to find appropriate industrial sites. After analyzing the aggregated difference of all land use types' relative presence after and before the industrial land transitions, regardless of the transition forms, the following observations are made: Industrial sites have negative effects on public facilities from 100 to 700 meters and social-cultural facilities in the 100-200 meters while positive effects on retail, recreation, and housing to appear within 800 meters.

The land use simulation model is constructed based on the land use interaction rules automatically extracted from computer-aided tools. Since the model is calibrated even though not optimized, it is directly applied to further scenario analysis for the new zoning plans. Zoning plans are imported into the land use simulation model, and simulated future land use situations are used for sustainability evaluation regarding land use situations which can help determine physical indicators of sustainability.

4.6 Redevelopment impacts on sustainability analysis

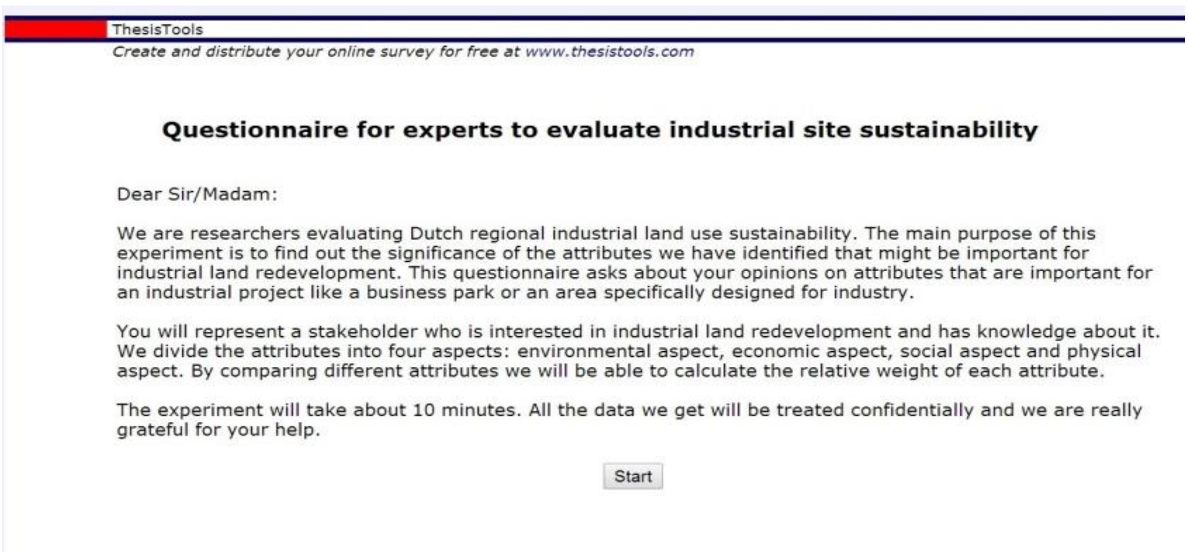
After a thorough literature review, the sustainability evaluation matrix is presented in Table 3.4.7. This can be used as a guideline for individual region or project to select from these indicators. The proposed framework has been validated by consulting the local industrial site redevelopment institution BOM (Brabantse Ontwikkelings Maatschappij, 2014), as explained in section 4.6.1. They use a similar sustainability evaluation framework. At this moment, not all the data for all the attributes to calculate indicators in our framework can be collected. Several attributes are calculated by applying FME® and ArcMap tools based on the available data collection. For the physical aspect in the framework, such as the distance to other land uses from an industrial site, FME® has been used to calculate percentages of land use types in the surroundings of 800 meters. The percentages are calculated for both before and after industrial site redevelopment. As a result, the consequences or impacts of industrial site redevelopment on the surroundings are calculated and analyzed, as explained in section 4.5.

Because of data limits, only several attributes are calculated to reflect relevant indicators in the evaluation system. These indicators are highlighted in Table 3.4.7 to illustrate the applicability of the proposed system. Our conducted interviews are in the early stage of our project, so the weights are used only for an illustration purpose. The main idea is to show how to use AHP method and to conduct such questionnaires to find the weights.

4.6.1 Interviews from the case study region

Experts and individuals are interviewed to discuss the presented matrix for industrial site sustainability assessment.

Three questionnaires are designed, namely experts to evaluate industrial site sustainability (questionnaire 1), experts to evaluation regional industrial sustainability (questionnaire 2) and private stakeholders to evaluate regional industrial sustainability (questionnaire 3). Respondents are therefore also different for each questionnaire. Alumni from the Built Environment department and their current colleagues are considered to be experts, which in total counts to 58 respondents. Individual stakeholders who are residents interested in this topic are asked to answer the third questionnaire. In total, we have reached 52 respondents. Online questionnaire designing tool www.thesistools.com is applied. One example of the questionnaire 1 is shown here; it uses pairwise comparison for every two indicators:


ThesisTools

Create and distribute your online survey for free at www.thesistools.com

Questionnaire for experts to evaluate industrial site sustainability

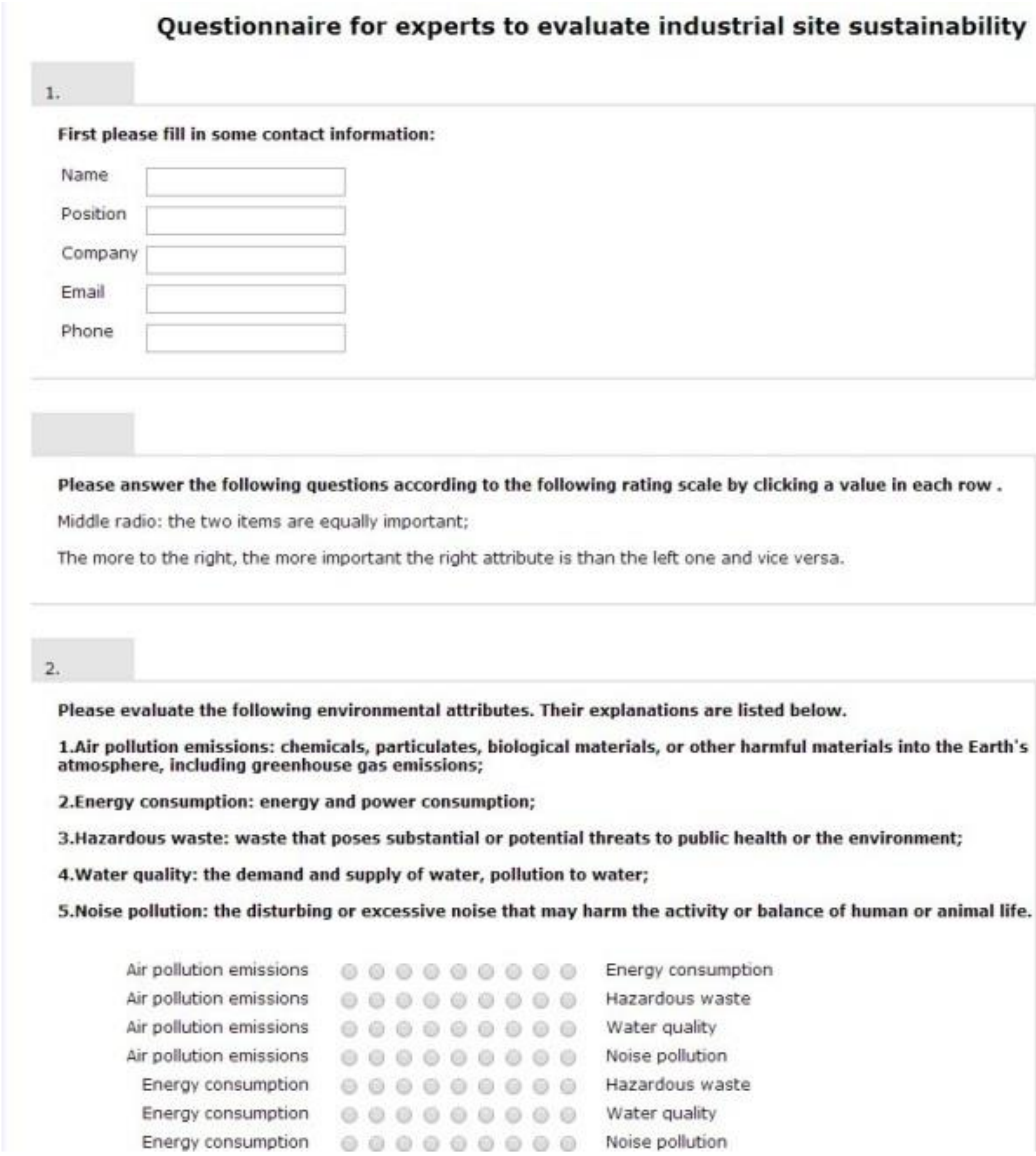
Dear Sir/Madam:

We are researchers evaluating Dutch regional industrial land use sustainability. The main purpose of this experiment is to find out the significance of the attributes we have identified that might be important for industrial land redevelopment. This questionnaire asks about your opinions on attributes that are important for an industrial project like a business park or an area specifically designed for industry.

You will represent a stakeholder who is interested in industrial land redevelopment and has knowledge about it. We divide the attributes into four aspects: environmental aspect, economic aspect, social aspect and physical aspect. By comparing different attributes we will be able to calculate the relative weight of each attribute.

The experiment will take about 10 minutes. All the data we get will be treated confidentially and we are really grateful for your help.

Start



Questionnaire for experts to evaluate industrial site sustainability

1.

First please fill in some contact information:

Name

Position

Company

Email

Phone

Please answer the following questions according to the following rating scale by clicking a value in each row .

Middle radio: the two items are equally important;

The more to the right, the more important the right attribute is than the left one and vice versa.

2.

Please evaluate the following environmental attributes. Their explanations are listed below.

1.Air pollution emissions: chemicals, particulates, biological materials, or other harmful materials into the Earth's atmosphere, including greenhouse gas emissions;

2.Energy consumption: energy and power consumption;

3.Hazardous waste: waste that poses substantial or potential threats to public health or the environment;

4.Water quality: the demand and supply of water, pollution to water;

5.Noise pollution: the disturbing or excessive noise that may harm the activity or balance of human or animal life.

Air pollution emissions	Energy consumption
Air pollution emissions	Hazardous waste
Air pollution emissions	Water quality
Air pollution emissions	Noise pollution
Energy consumption	Hazardous waste
Energy consumption	Water quality
Energy consumption	Noise pollution

Figure 4.6.1. Questionnaire example

4.6.2 Weight determination from the questionnaire

Experts are interviewed, and weights for these indicators are determined based on the Analytical Hierarchy Process (AHP). The procedures to calculate these indicator weights are standard according to AHP method, including pairwise comparison matrix construction, maximum Eigenvalue calculation, consistency ration calculation and weight vector calculation if the consistency ratio (CR) is acceptable (where CR < 0.1). Because of the limited data, only the weight for each indicator on the site level is presented here without really calculating sustainability values because we cannot get all the data to calculate all the indicator values. The purpose here is to show that using AHP; weight can be obtained for each indicator for further total sustainability evaluation on the site and regional level. Further research can gather more data to thoroughly evaluate scenario's site and regional sustainability total score.

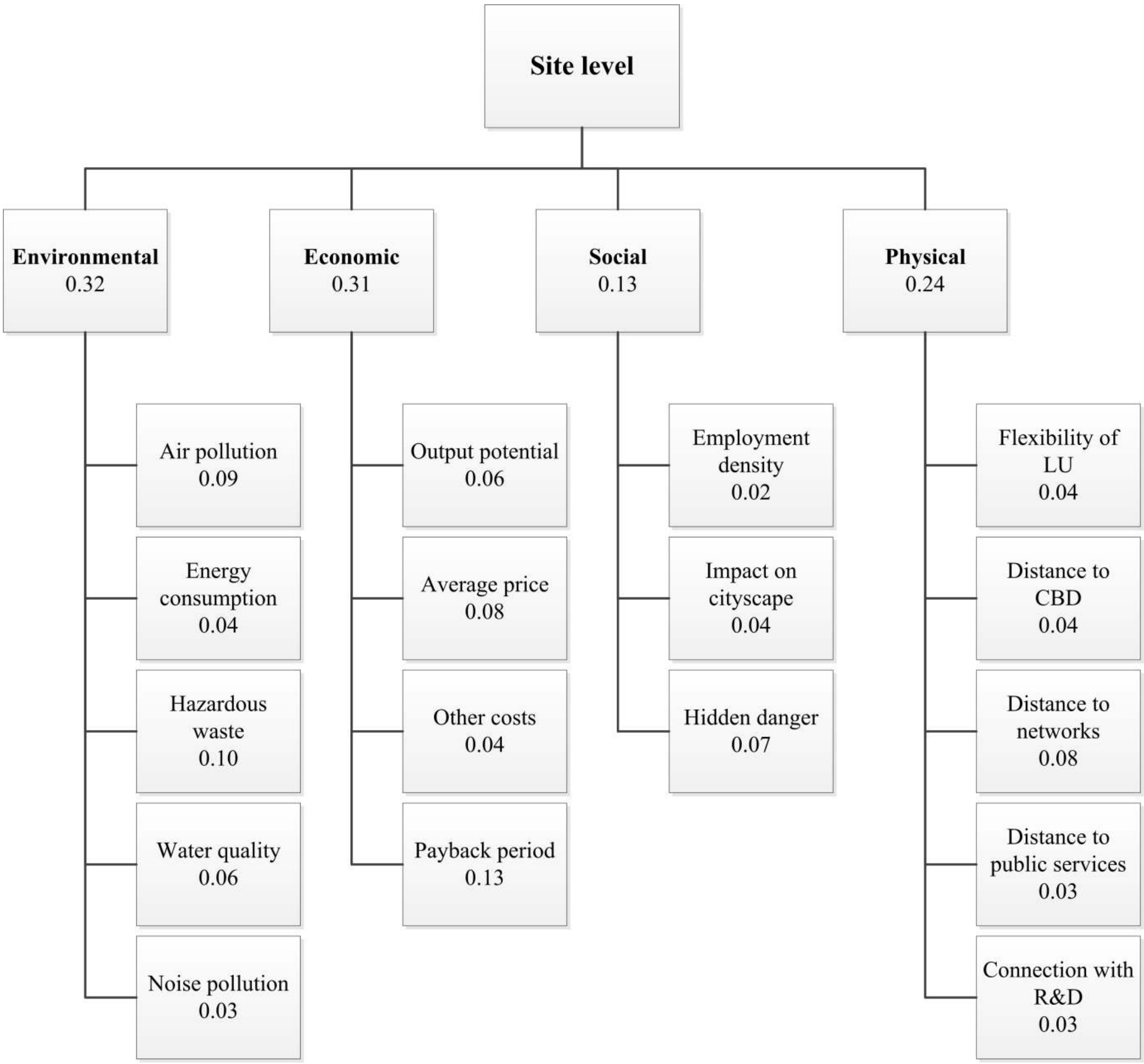


Figure 4.6.2. Site level indicator weights for AHP

4.6.3 Impact on regional level sustainability

After the incorporation of the new zoning map, several maps to reflect regional indicator changes are illustrated here. No real value is presented since these indicators need to be calculated based on predefined algorithms which are beyond the scope of current practice for this research, but instead more vivid maps are presented to show the regional impacts in a spatial context. Please note that these maps are not of the same size since we would like to emphasize the changed part more clearly for each indicator. Sealed soil map is used to reflect the soil condition after the transition, as shown in Figure 4.6.3.1. From this figure, it is clear that after the industrial transition from heavy industry to light industry, public facilities and residential areas, a large amount of sealed soil is reduced on the site and its nearby neighbourhood, which gives a positive impact on the whole regional soil condition.

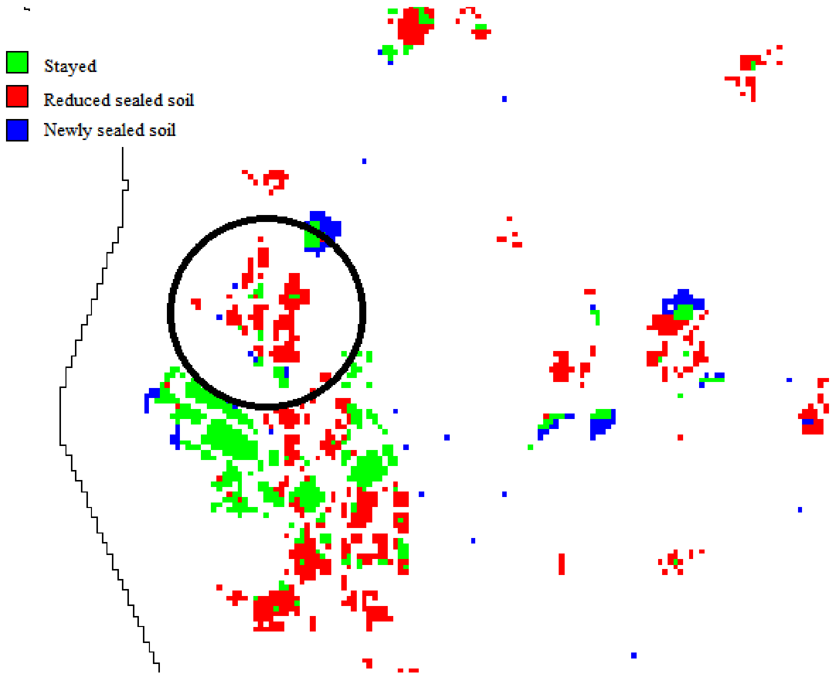


Figure 4.6.3.1. Regional environmental indicator: soil condition

The employment rate is used to illustrate the regional economic indicator as shown in Figure 4.6.3.2. It is assumed that new industry generates jobs on public facilities than old abandoned industrial sites. Based on the land use simulation result and our assumptions, listed in Appendix E, employment density was 75-85 persons per hectare. This has been increased near the site, however, based on the site level calculation (shown in section 4.6.4), the total number of employee is reduced. This shows that industrial land is more efficiently used after the transition since land is used more intensively for working purpose.

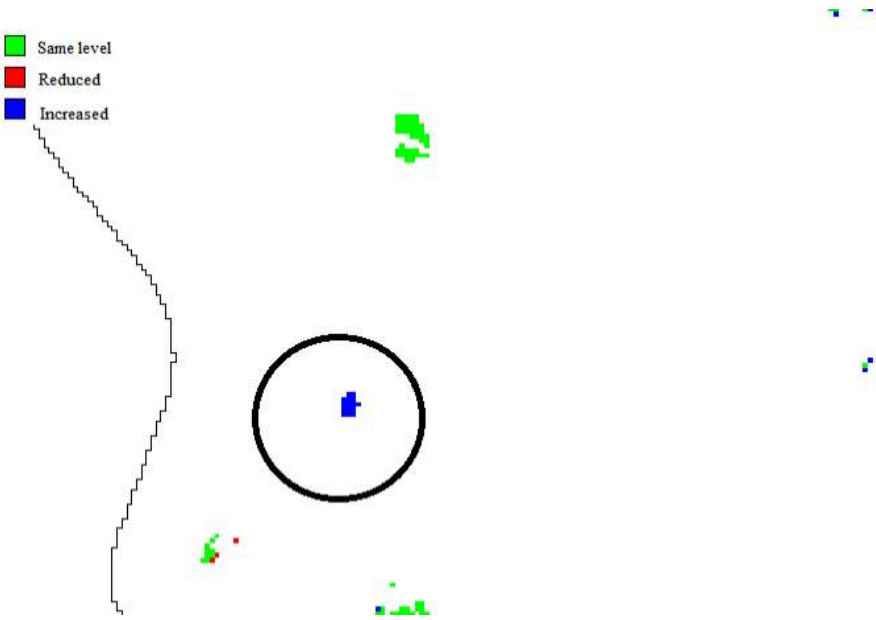


Figure 4.6.3.2. Regional economic indicator: employment level

Urban clusters and urban expansion maps are used to represent spatial segregation level to reflect regional social indicator for sustainability evaluation. Figure 4.6.3.3 shows that after the redevelopment of such industrial area into housing, more urban areas will come in the near neighbourhood, so as more urban areas and residences.

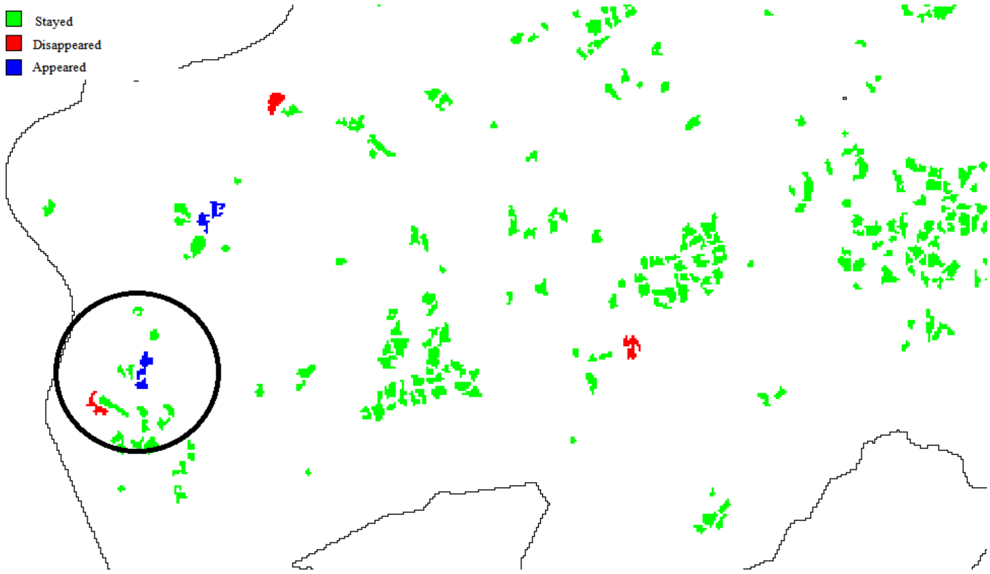


Figure 4.6.3.3. Regional social indicator example: urban clusters

After the redevelopment of such designed mixed-use functions, more urban functions come to the nearby area, as seen in Figure 4.6.3.4, which can be evaluated by the policymakers whether this is good or not based on their regional visions.

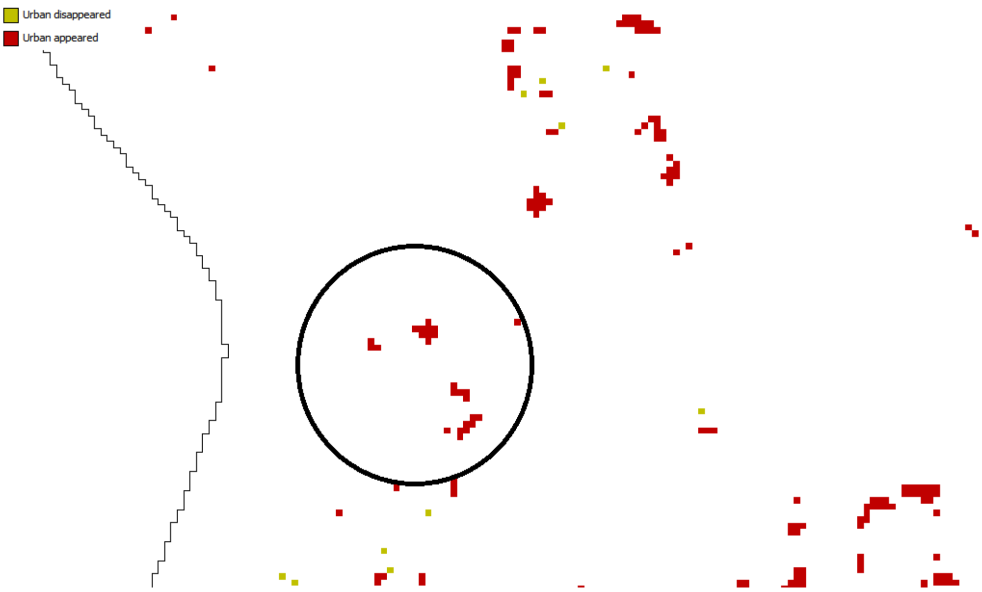


Figure 4.6.3.4. Regional social indicator example: urban expansions

Residence density and distance to work maps are used to illustrate population density indicator and the accessibility to work indicator respectively. Figure 4.6.3.5 shows that population density has increased in the category of 50 and 65 people per hectare.

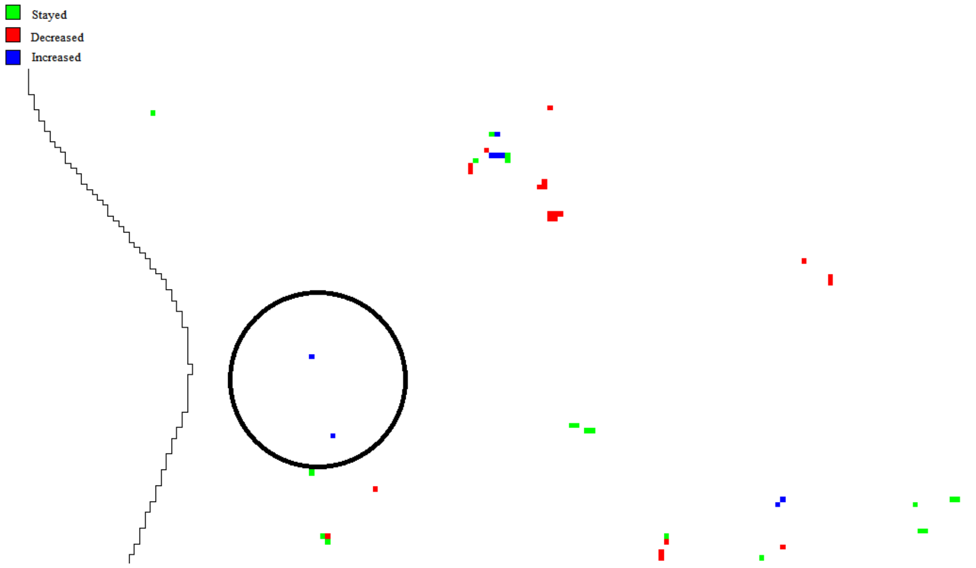


Figure 4.6.3.5. Regional social indicator example: residence density change

As shown in Figure 4.6.3.6, distance to work has been reduced by average 500 meters based on the land use simulation result on the site and also on the southern part of the site because of the newly developed housing and newly redeveloped industrial area on the site. As a result, the accessibility to services and work is improved, and this also explains why population density is increased in the neighbourhood.

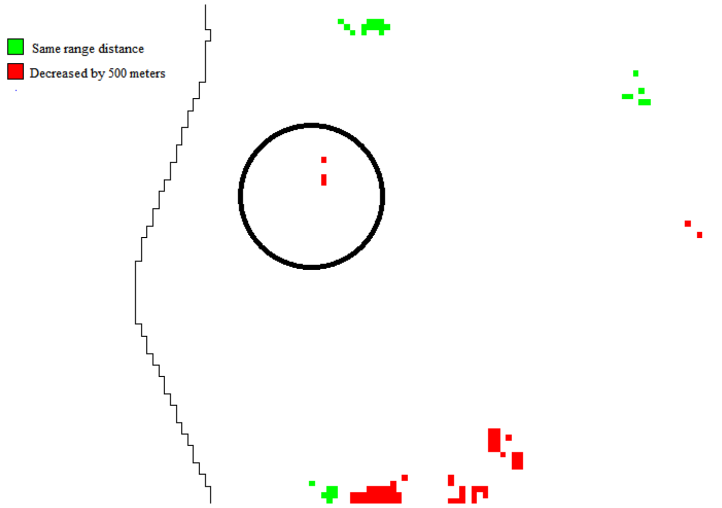


Figure 4.6.3.6. Regional social indicator example: distance to work

Other indicators are also dynamically updated. The redevelopment plan has impacts on the regional sustainability indicators including but not limited to these illustrated indicators. We have also specifically analyzed the influence of such redevelopment plans on regional land use compositions- one of the reflections of regional physical indicators, as discussed in section 4.5.

4.6.4 Impact on site level sustainability

To evaluate target site redevelopment practice impacts on the site level, the similar cases retrieved from section 4.3 are consulted. For case 1, Victoriapark, mainly everything is transformed into housing, while for the other case, Drie hoefijzers, there are also office buildings and facilities added. In our study, their average outcome for the sites is used to evaluate the site level sustainability, after being normalized based on the site sizes. Detailed zoning plans for these two sites are in appendix D.

Several indicators are calculated based on attribute values, and the comparison is provided here. Assumptions based on the normalized value from the two similar cases are used. For example, assuming case one attracts 1000 people come to the newly designed site for an area of 100 square meters, and case two attracts 2000 people come to the site for an area size of 400 square meters, then the average attraction rate for each square meter for such design is calculated as ½ (1000/100+2000/400), which equals to 7.5 per square meter. This number is used for the new site to calculate how much population is going to be attracted to the new site based on its size. Detailed assumptions and the calculation process are in appendix E. Several calculated attributes (also can reflect the values of indicators in the list) are listed below.

1. Noise pollution: according to Carsjens and Ligtenberg. (2007) after the removal of the heavy industry from the site, noise pollution impact zones can be largely reduced. They have used the VNG list (Brunner & Bruinsma, 2009), where it shows the impact zones of various impact categories namely smell, dust, noise and danger according to activity types, to make this conclusion. One of these impacts, which is the changed noise impact zones, is illustrated in Figure 4.6.4. This is based on the reuse of concrete for construction factory (SBI code 60221) from the site to a motorcycle factory (SBI code 6420) since the surrounding industrial activities mainly do motorcycle related businesses. In this way, the industry can be better facilitated. For previous use of construction concrete production, the impact zones have a buffer distance of 300 meters, resulting in an impact zone of size 45.4 hectares. And after reuse, this facility into a motorcycle factory, the impact zone of noise is reduced to 3.3 hectares since the impact buffer distance is reduced to 30 meters from 300 meters according to the VNG list.

2. Payback period: for case drie hoefijzers, it takes 12 years while for Lichtoren project it takes 6 years. We have averaged these two cases and give our target site payback period 9 years. This is a rough estimation which of course can be improved based on specific situations. Here it is only to show the use of CBR in estimating possible duration based on past experience.
3. Employment: it is assumed that before redevelopment, there are very few employees for industrial while afterwards more employees are needed for the newly built public services and industry. Based on the assumptions, before the redevelopment, there are 21 jobs on the site while 146 jobs after.
4. Distance to public services is 0 meter after the transition since public facilities are now presented on the site while before it was 500 meters based on the calculation in the GIS environment.

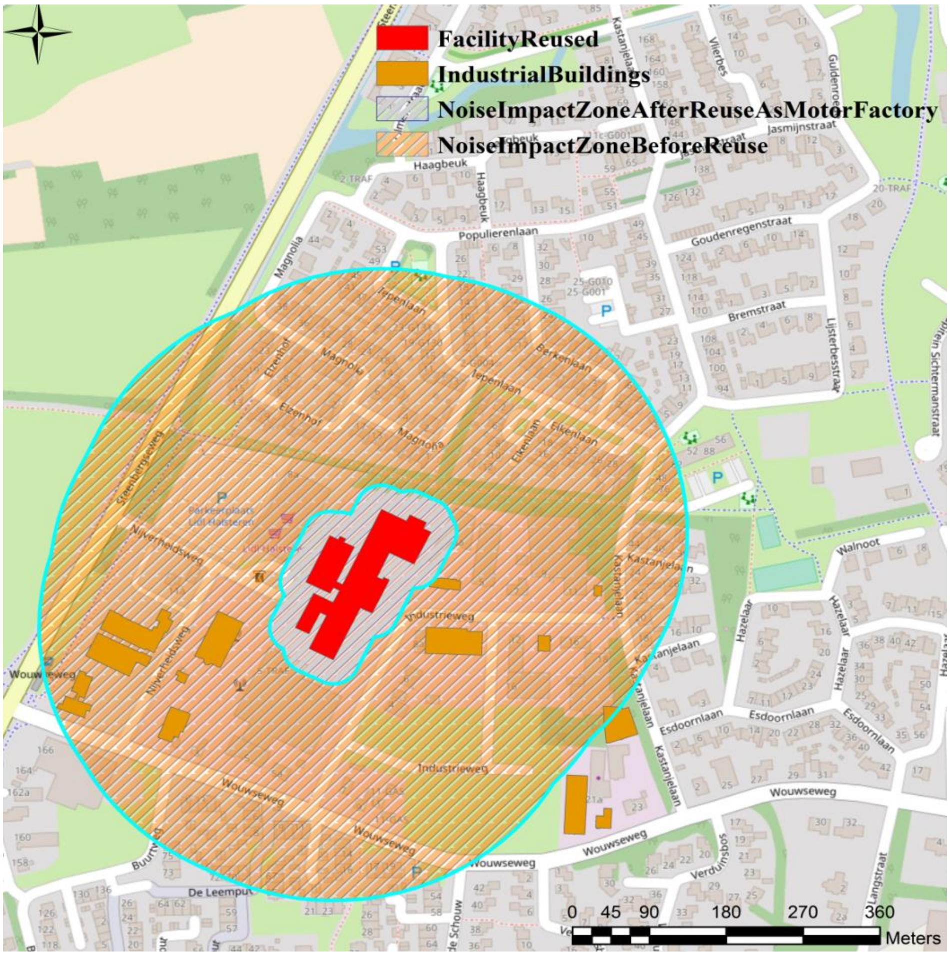


Figure 4.6.4. Noise impact zones before and after the facility reuse

4.7 System validation

In reality, this selected site already has a zoning plan, and the target use is residential area combined with facilities and industry. The target site's detailed master plan is in Appendix F. Figure 4.7 shows the comparison between real site design and the scenario design based on the system output. From the comparison, it is clear that on the west side of the site, public facilities are presented and on the southern part of the site, housing is accommodated. For the east side, the working function is emphasized, so as the working related living spaces. In our design, the mixed function is simplified by giving a simple function for each part of the site. However, in general, the location of functions from the design matches the reality.

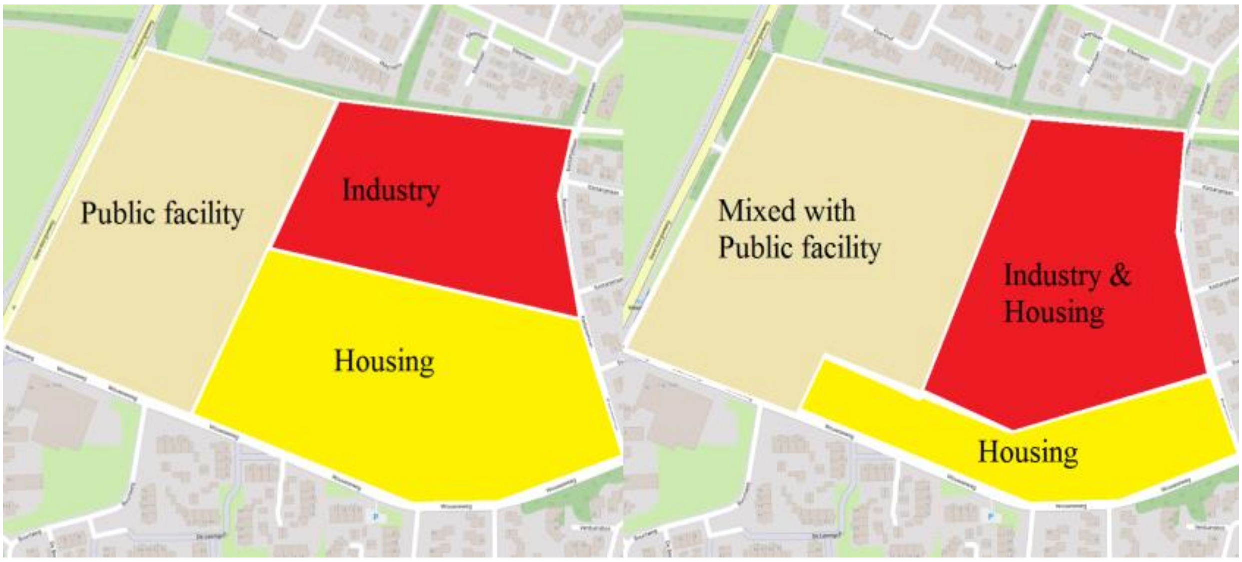


Figure 4.7. Comparison between design and reality (left: designed scenario; right: reality)

Table 4.7. Each function's size based on the real zoning plan

Destination	Surface sq meters	Percentage	Designed scenario
Industry	43.453	42.24%	21.5%
Mixed	25.196	24.50%	
Green	5.909	5.74%	40.7%
Traffic	17.036	16.56%	
Living	11.267	10.95%	37.8%

Specific outcomes according to the zoning plan are listed in Table 4.7. In our proposed plan, 9.3 hectares are designed as living (37.8%), 10 hectares (40.7%) as public facilities including green areas and other services and 5.3 hectares (21.5%) as an industry. Even though the numbers shown in Table 4.7 do not really reflect the correct percentages, at this moment, it is considered that our system can be used to design the site in the same way. For one thing, the locations are roughly the same for different functions. For another, only a simple design process that only draws lines based on the existing building footprints without considering demolishing is applied. Thirdly, the public facility is used as a general name that includes green spaces, mix uses and traffic networks as proposed by the real zoning plan.

4.8 Conclusions for the case study

This chapter presents a case study using our proposed SIRPSS. Data acquisition and integration are discussed, followed by target site selection for redevelopment design. The target site is selected by combining BIM and GIS data to help reuse facilities. Similar cases are found in the knowledge-based system using a CBR approach. Regional specific case library is constructed. To identify the redeveloped industrial sites, FME scripts are used to automatically detect the transformed industrial sites and their associated zoning plan documents. In total 39 Dutch industrial areas redevelopment cases are examined. For each of them, their most mentioned visions in the zoning plan documents are identified using natural language processing tools. The manual selection procedure is included to ensure that only the domain-specific visions in the industrial site redevelopment planning process are included. In general, this region focuses on redeveloping industrial sites to provide housing accommodation for expats and students and to attract new business.

Similar cases are compared with the target site at hand to have a reasonable design for the new case. This design is then imported into the calibrated land use change simulation model to see future land use dynamics. The calibrated land use model is developed with the help of a neighbourhood rule distraction tool. During the development process, the analysis is performed to understand regional land use transition situations. This supports evaluating regional sustainability in the future, addressing physical aspects, together with other attribute values gained from either case base library or calculation based on data acquisition. Similar past cases' zoning plan documents also referenced to evaluate site level sustainability. SIRPSS system is validated based on the real site design. At this moment, only very limited validation can be provided considering time limits and data limits. Further workshops are necessary to get feedback from real users for industrial site redevelopment practice.

From the proof-of-concept implementation presented in the previous section, it can be seen that this framework and system can be modified and applied in other areas once the data is available. Therefore, it is possible in future research to verify and validate the applicability by means of a case study in a specific area with actual stakeholders, preferably with the help from local governments to acquire the necessary data.

CHAPTER 5 CONCLUSIONS AND DISCUSSION

This chapter starts with the summary of this research by answering the research questions raised in section 1.4. The proposed planning support system is summarized, and the contributions of this research are emphasized afterwards. In the second part of this chapter, the current limitations of this research, and future research are discussed.

5.1 Summary of the research

A significant number of abandoned or underused industrial sites need to be redeveloped; to this end, computer-aided tools such as PSSs can help in planning process.

5.1.1 Industrial site redevelopment and planning support system-SIRPSS

The main research question is: how to support redeveloping industrial sites with vacant facilities within a region in a sustainable way based upon experience and holistically assess redevelopment impacts on site and regional sustainability?

To support facility reuse for industrial site redevelopment and evaluate sustainability impacts of the redevelopment plans on both site and regional level and referencing experience, a PSS called SIRPSS is proposed. SIRPSS is a dynamic, long-term, multi-level scale system that can be used by various parties. It can be easily tailored for different cases because of its parameter-driven characteristics, as new cases can be collected and stored using the developed computer tools. It can be used throughout the lifecycle of an industrial site's redevelopment process and can encourage the use of planning support systems not only in the research field but also in practice. A region can strengthen its competitiveness by offering such a system to individuals to allow them to visualize their own plans for the site. By involving different parties in the planning process and dynamically evaluating different scenarios from multiple levels, we aim to reduce barriers to the successful implementation of this system.

To summarize the system, the first sub-question is also answered: How to construct computer-aided tools such as planning support system (PSS) to improve regional planning tasks, regarding industrial site redevelopment? What components does it contain?

SIRPSS has four components (modules): a multilevel data integration module, a case library, a land use change impact analysis and simulation module and a holistic sustainability evaluation module. The data integration module applies various data sources to find similar cases that have been redeveloped in relation to a selected target site. For this purpose, a case library, including the experience of industrial site redevelopment, has been constructed. SIRPSS references existing redevelopment cases to inductively reason possible redevelopment scenarios and processes for the target site, which serve as the starting point for further discussion among stakeholders. The chosen redevelopment strategies for the target industrial site, together with the market demand for different land use types, is the input for the land use change simulation module, which seeks to provide dynamic information regarding land use conditions and to further help in the evaluation of related physical sustainability indicators. Attribute values generated from the simulated land use modelling process, together with other sustainability indicators from social, economic and environmental aspects, are then further analyzed and visualized in the sustainability evaluation process.

5.1.2 The core of SIRPSS: a case library

The second sub-question then raises: how to construct a case library which stores past industrial site redevelopment experience?

To support policymakers in designing and determining a redevelopment strategy for industrial sites, a case-based reasoning approach has been proposed that enables users to learn from past. This makes this PSS different from other PSSs since it is a self-enriching system. The theoretical background of case-based reasoning is reviewed for the urban planning domain as well as for other domains. As a result, a case representation structure is developed. A case is described by combining qualitative visions for redevelopment and quantitative attribute values, with the solution being presented as the transition form for industrial sites. The problem to be solved is to choose the most plausible sustainable transition form for a new industrial site through finding similar past redeveloped cases. Furthermore, the impacts of redevelopment are reflected by the proposed case representation structure by using dynamic temporal information which records attribute values before and after redevelopment. As a result, the redevelopment impacts on the surroundings are also described. This case representation structure is also in line with the proposed sustainability assessment framework, i.e. each indicator that can be evaluated based on attribute values can be reflected in the case structure. Based on the new case at hand, visions and specific requirements are provided by the users to find similar cases from the regional case library. Past experiences, regarding the strategies used in, and the impacts of, such redevelopment, are imposed onto the new case at hand; as a result, scenarios are designed for the new case, in addition to sustainability impacts being evaluated at both site and regional levels. The research presented in this study offers a novel retrieval mechanism and an easily adaptive tool for finding cases in a target region where social, economic, physical, and environmental conditions are similar.

5.1.3 Multilevel data integration

The third sub-question is then answered based on the proposed CBR approach: how to find the most suitable redevelopment sites from a region based on stakeholders' preferences and find similar cases from the library, using both geospatial data and building information?

In this research, literature study has been conducted to identify the most important attributes both for building and site levels in relation to facility reuse on industrial sites. GIS and BIM data have been classified based on the scale, source, and types. To integrate geospatial information and building information, the theoretical background has been illustrated considering data formats, integration possibilities and our choice for the scope of this research. Building information has been added to the commonly applied geospatial data for the suitability calculation process. An approach is illustrated which uses loosely coupled data from GIS and BIM on the GIS platform. Using this approach, a target site has been selected in the GIS environment using suitability analysis. The suitability has been calculated based on the sum of weighted attribute values generated from both GIS and BIM data sources. A profiling approach has been also presented to match existing facilities on industrial sites to the desired facilities but not implemented in this research. This approach could be implemented once more BIM models become available for existing buildings.

5.1.4 Industrial land transition impact analysis and modelling

To help evaluate physical impacts of such redevelopment, the fourth sub-question needs to be answered: how to construct a land use simulation model to represent the past land use dynamics and predict future possible land use situations?

A land use change simulation model has been constructed and applied which helps to understand the trend of land use changes and predict future land use situations. To accelerate the time-consuming calibration process of commonly applied cellular automata land use models and to solve the problem of information loss in the raster map analysis, a straightforward data mining approach has been developed to analyze vector land use maps based on parcel shapes and to derive neighborhood rules. Furthermore, a detailed understanding of the transition impacts and the factors that drive land redevelopment in terms of surrounding land use compositions is achieved by analyzing holistically regional industrial site transition on the basis of physical data. The analysis process finds out four aspects of industrial land transition, namely: the inertia for industrial sites to remain; the surrounding land use compositions that cause industrial site to appear and the impacts on the surroundings of such changes; the most frequent transition forms of industrial sites and the impacts on the surroundings for each industrial transition form. Because of the empirical essence of the proposed approach, it is generic and applicable to other areas. No expert knowledge is needed for setting neighbourhood rules in the process unless fine-tune is required.

5.1.5 Holistic sustainability evaluation

After constructing the calibrated land use change model, the fifth sub-question can be answered: how to holistically evaluate the future sustainability on site and regional level which incorporates the new design for industrial site redevelopment?

Based on the literature review, a sustainability evaluation matrix is constructed on the site and regional levels. This matrix contains four aspects of sustainability evaluation, namely, the economic, environmental, social, and physical aspects. To illustrate the possibility of evaluating sustainability using SIRPSS according to these four aspects, the North Brabant region in the Netherlands is used as a case study. The target site redevelopment zoning plan is incorporated into the calibrated land use change model so that future land use situations can be generated. These generated future land use maps help to evaluate and visualize physical related sustainaiblity indicators on a regional level. Several other sustainable redevelopment indicators are also illustrated on the site and regional levels by referencing the case library and using assumptions based on literature study. These indicators are in the form of attribute values, which can later be integrated into one indicator value, together with a user-defined weight when more data is available.

5.1.6 Project societal and scientific contributions

The planning process proposed in this research aims to make the urban planning process more transparent by involving both public and private parties. As a result, stagnating industrial site redevelopment problem can be solved by raising enthusiasm from both public and private parties. Possible failure can be identified from the early planning phase which supports to reduce the costs of regional planning tasks. Facility reuse is also emphasized to reduce construction costs and pursue for a sustainable future. Better images for a region can be realized by changing abandoned industrial sites into fully functional vivid areas. A region can strengthen its competitiveness by offering such kind of system to allow individuals visualizing their own plans for the site.

Scientifically, a planning support system is developed which provides suitable redevelopment site selection, similar case retrieval, customized parameter settings, land use dynamic prediction and site and regional level sustainability evaluation functions. Visualization is also possible via maps and interactive web applications.

This research contributes in the following aspects: multilevel data integration, case-based reasoning, land use change impact analysis and modelling and holistic sustainability evaluation. As has also been claimed that PSS has the potential to increase the objectivity and accuracy of sustainability assessment, enhance both the understanding of environmental and planning considerations and the delivery of information, and therefore, help to improve the effectiveness of land use planning practices (González et al., 2011). The system is developed in a way to connect regional geospatial information to detailed site redevelopment lifecycle information. SIRPSS is dynamic, long-term, multi-level scale system and can be used by various parties. It can be easily tailored for different cases because of its parameter driven characteristics as new cases can be collected and stored using the developed computer tools. It could be used through the life cycle of industrial area redevelopment process. It could raise the enthusiasm for using the planning support systems not just in the research field, but also in practice. By involving different parties in the dynamic planning practice and evaluating different scenarios dynamically from multi-levels, the hinders of successfully implementing this system could be reduced.

Multilevel data is integrated to combine regional visions and site level detailed information. Different formats of GIS and BIM data are discussed and a profiling approach is proposed to combine different data sources, especially in finding a suitable facility for reuse which is desired for facility reuse on industrial sites (Rich & Davis, 2010) and this combines both public government interests and private developers' specific requirements.

Case-based reasoning (CBR) approach is applied in urban redevelopment planning field for finding similar cases in the past from the same region. A case representation structure is proposed to describe each industrial site redevelopment case. With the proposed case representation structure, regional and site characteristics can be coupled in a coherent manner. Experience in industrial site redevelopment could be stored, retrieved and learned for the new tasks. A novel and effective way to incorporate CBR into the industrial site redevelopment process is presented which illustrates what should be the input and output for each procedure of industrial site redevelopment. Similar case retrieval algorithm is proposed by combining qualitative visions and quantitative attribute values, following the proposed case representation structure. The use of automated methods to analyze zoning plan documents is proposed which is more efficient than analyzing each zoning document by the users (Wang, et al., 2015). By analyzing data embedded in textual documents, new knowledge and patterns are extracted that would otherwise have remained hidden. To enrich the case information besides visions, the most influential attributes which determine the industrial site transition forms are identified, using machine learning approach from a large dataset. To design the target site, the geospatial environment is analyzed which follows the Geodesign process by integrating the physical environment into the design consideration which tightly couples the creation of design proposals with impact simulations informed by geographic contexts, systems thinking and digital technology (Steinitz, 2012). In the meanwhile, the comparison study between the target site and the past cases help to find the most suitable redevelopment strategies as well. This is an inductive reasoning process which helps to improve the decision process among stakeholders.

Detailed land use interaction analysis, specifically for analyzing land use transitions is presented. This provides a framework for analyzing surrounding land use compositions impacts on land use transition and vice versa. After the analysis, the regional specific land use change simulation model is constructed. The constructed and calibrated land use change model is used for simulating future land use situations by integrating new industrial site redeveloped plans. The outcome of land use simulation models is used to evaluate future land use related sustainability indicators which helps to evaluate the whole industrial site redevelopment life cycle as claimed by Yeo, Yoon and Yee (2013). Computer-based tools are developed to find regional land use interaction rules to construct and calibrate CA land use simulation models.

Holistic sustainability evaluation is performed. Regional and site level indicators are combined to evaluate the proposed industrial site redevelopment strategy for the target site. A regional specific indicator system is developed based on literature review and validated by workshops with local stakeholders. Weights for each indicator are also derived based on questionnaire results. Regional and site level indicators are evaluated based on the proposed industrial site redevelopment strategy, referencing experience from case library. Nuissl *et al.* (2009) have also argued that two levels of impact assessment for land use transitions are necessary: the level of the single land unit (site) level and the context (regional) level which takes into account regional and aggregated impacts of land uses transition bound to the spatial context.

5.2 Limitations and future research directions

In this section, the limitations are illustrated from five aspects and several possible future research directions are identified.

5.2.1 Limitations

First limitation is about industrial land itself. For one thing, this research focuses on not fully used industrial sites only, while the industrial sites that have never been used are not included since there are no facilities available. For another, the future land use demand is estimated based on trend extrapolation. However, the accuracy is expected to deteriorate with time as no causal factors are considered. Thirdly, the industrial site is stated as one land use type; while it can be argued that industrial sites can be subdivided into several categories such as high-tech campus, heavy industry, light industry, creative industry and others. Lastly, regarding land use data, currently, the implementation part does not use the same period consistently because of the limitation of data[11].

Second limitation is about designing the target site. In this research, we have applied inductive reasoning to design target industrial sites based on experience from the case library. The assumptions are that the used strategies can also be applied to new tasks in the same region because of the same regional characteristics. However, this type of reasoning has the disadvantage of being inaccurate because of different judgements from policymakers for historical cases and different analysis approaches applied when there are varieties involved (Khattak & Kanafani, 1996).

Third limitation is about using only the retrieval process of case-based reasoning. Case-based reasoning is a self-learning system which requires more information of cases and more processes of CBR to be added, such as review, reuse and retain as discussed before (Aamodt & Plaza, 1994; Biswas, Sinha, & Purkayastha, 2014; Kolodner, 1993).

Fourth limitation is regarding sustainability evaluation, at this moment, only very limited indicators are calculated for the lack of data. Combining indicator weights with real indicator

[11] For land use simulation modelling, we have used land use maps data from the year 2000, 2008 and year 2012 since these three datasets provide both consistent data precision and long timespan. However, in 2008, a severe economic crisis happened which influences a lot in the land use development process. During the calibration process, this makes the model very difficult to be calibrated and might cause problems regarding validity of the data.

values to evaluate a total sustainability score for each scenario need to exploit the full potential of SIRPSS.

Last limitation is about PSS itself. From the point of PSS view, the whole system runs in a standalone GIS environment instead of on the cloud or on the web which gives a better access to the potential stakeholders (Batista e Silva et al., 2014; Lei, et al., 2017). Moreover, the development of a PSS is a process in which developers and users should work together (Vonk, Geertman, & Schot, 2007). Advanced PSSs' potential can only be realised if planners and system developers start to share knowledge and demands and identify opportunities in a cooperative PSS-development process (Vonk & Geertman, 2008). However, in this study, it is not the current focus.

5.2.2 Future research directions

Six directions for future research are identified, namely industrial site redevelopment problem itself, multi-level data integration, successful redeveloped case identification, case-based reasoning in urban planning, sustainability evaluation for industrial site redevelopment and planning support system research.

5.2.2.1 Industrial site redevelopment problem

Firstly, future research can address redevelopment potentials for completely empty industrial sites instead of industrial sites with disused facilities. Instead of redevelopment and reuse of the site or the facilities, this type of industrial sites might be more suitable for the development of various land use types.

Secondly, future research can apply regression models and density measures so as scenarios with more inputs from economic factors, as reviewed by Silva *et al.* (2014), to predict future land use demands. Currently, the Netherlands currently has one of the most sophisticated industrial land demand forecasting models, to predict future land use needs based on scenarios (Centraal Planbureau, 2002; Traa & Declerck, 2007), which is called business-housing location monitor (Dutch: Bedrijfslocatiemonitor; BLM). However, this method is with criticism, as claimed and proved by Beckers and Schuur (2015) that only using employment as the predictor for industrial land demand is not sufficient. As a consequence, Dutch municipalities tend to apply more localised forecast methods to predict future industrial land demand (Ploegmakers & Krabben, 2012).

Lastly, future research can address more detailed industrial land use types to get more insights for regional industrial site redevelopment process. For example, heavy industrial sites which are contaminated are probably not suitable for residential land while other types of industrial sites might be suitable. Xue *et al.* (2016) have stated this approach for brownfield redevelopment exercises in China by proposing an extended coding system for land use types. A sub-type of industrial land redevelopment (coalfield) case study is presented by Burke *et al.* (2015), so as a case study for the creative industry by He & Gebhardt (2014).

5.2.2.2 Multi-level data integration

New research could focus on the database development using, for example, PostGIS, adding more possibilities such as cloud service and functionality using mature PostGIS extensions and providing APIs to automatically add new cases using pre-written scripts from other sources.

Another possibility for research is to consider using MongoDB (Dirolf & Chodorow, 2010) to support the use of case-based reasoning because of the flexibility MongoDB provides for descriptive textual texts for each industrial redevelopment site in a region.

5.2.2.3 Successful redevelopment case identification

In future research, the detection of successful redeveloped industrial sites can be investigated based on pre-set rules for surrounding land use composition changes. For example, it could be imagined that after a transformation, the surrounding industrial area percentage increases. It could be argued that the redevelopment process of that area is successful, provided that more industry comes nearby. If aiming for a greener environment, one can judge the redevelopment scenario by the changes of the advent of green or leisure areas in the surroundings. In other words, from analyzing surrounding composition changes of land use maps, it is possible to detect successful redevelopment cases.

Other novel approaches besides land use analysis perspective to determine successful or satisfied redevelopment cases can be researched. One example is presented by van der Hoeven and Juchnevic in which good practice of urban underground station design was produced, using reference design cases based on the opinions of users, peers and critics, through the use of social media, via recognition in prizes and awards and through indexed architectural periodicals (van der Hoeven & Juchnevic, 2016).

5.2.2.4 Case-based reasoning in urban planning

The case library can be enriched with more mathematical or theoretical base to find the most influential attributes for industrial site transition, such as the examples given by Green (2018) and Martinat *et al.* (2018).

Future research can also examine the other three procedures in CBR. For example, how to revise a transition form from a previous case based on the current situation. Algorithms can be tested for revising the solutions in a satisfying way. Automatic case library update could be added to the system by providing application programming interface (API) to the tools that are currently used: Metronamica, ArcMap and CommunityViz.

5.2.2.5 Sustainability evaluation for industrial site redevelopment

One research opportunity is to assess sustainability automatically for a given indicator set by following the framework presented by Schädler *et al.* (2013). In relation to this, possible automatic optimization of land use options for industrial site redevelopment design could be studied to improve the applicability, comprehensiveness, and reliability of the indicator-based evaluation of sustainability.

On the other hand, the circular economy concept can be added and to facilitate industrial activities in an urban environment to use waste as materials for different parties and be more sustainable. To fulfil this purpose, a digital database can be constructed which connects the stakeholders from upstream to the downstream of the industrial processes. Site design process can be implemented by applying a co-creation approach, which also helps improve sustainability.

5.2.2.6 Planning support system

Future research can examine the usability of the system in practice. Multi-criteria analysis is then also possible, providing participating stakeholders can give weights for the attributes. Since the system supports scenario designs, trade-off analysis between solutions that reconcile different interests could be facilitated. Future study could also follow a practical approach that tries to improve the collaboration between future users and the developers and afterwards quantify the improvement of PSS use such as the example given by Brömmelstroet (2012).

Additionally, the system is currently implemented on commercial software like ArcMap, FME, CommunityViz and Metronamica. The following step could be using open source software such as QGIS, R, and Land Use Scanner. Public participation in sustainable industrial site redevelopment could then be investigated using open source software.

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APPENDIX A LIST OF PROMINENT ATTRIBUTES FOR FACILITY REUSE

Attribute		Data source	Category
General			
G-1.1	Acquisition costs / rental price[3,4,5,6]	Manual	Numeric, specified in local currency [f]
G-1.2	Maintenance cost	Manual	Numeric, specified in local currency [f]
Building			
Layout / structural			
B-1.1	Net floor area[1,3,5]	BIM	Numeric, specified in square meter [f]
B-1.2	Restroom floor area[2,6]	BIM	Numeric, specified in square meter [f]
B-1.3	Architectural openness / flexibility[3,5, a]	BIM	Numeric, ratio of spatial partitioning [f]
B-1.4	Building height / visibility[1,3,5]	BIM	Numeric, specified in meter [f]
B-1.5	Ceiling height[2,3,4,6]	BIM	Numeric, specified in meter [f]
Period			
B-2.1	Year of construction[1,4]	BIM, GIS	Numeric [f]
B-2.2	Last renovation year[1,4]	GIS	Numeric [f]
B-2.3	Vacancy period[4]	GIS	Numeric [f]
Entrance, accessibility, circulation			
B-3.1	Private entrance[1,6]	BIM	Boolean
B-3.2	Reception and waiting area[1,2]	BIM	Boolean
B-3.3	Loading bay[2,6]	BIM	Boolean
B-3.4	Accessible for the disabled[2,3,4]	BIM	Boolean
B-3.5	Capacity of lift[2]	BIM	Numeric, specified in persons [f]
B-3.6	Security provisions[2,5,6]	BIM	Boolean
Comfort / climate			
B-4.1	Heating, ventilation and air conditioning [1,2,3,4,5,6]	BIM	Boolean
B-4.2	Average lighting level[2,3,4]	BIM, simulation	Numeric, specified in lux [f]
B-4.3	Projected average energy consumption[3,4,5,6]	BIM, simulation	Numeric, specified in kWh [f]

B-4.4	Fire safety installation, sprinklers[3]	BIM	Boolean
Facilities / amenities			
B-5.1	Catering in building (pantries or restaurant)[1,2]	BIM	Boolean
Plot			
Layout			
P-1.1	Site area[3]	BIM, GIS	Numeric, specified in square meter [f]
P-1.2	Built - unbuilt ratio[3]	BIM, GIS	Numeric, ratio [f]
P-1.3	Parking area[1,2,3,4,5,6]	BIM, GIS	Numeric, specified in square meter [f]
Accessibility			
P-2.1	Street type at entrance	GIS	Nominal
P-2.2	Security provisions[2,5,6]	BIM, GIS	Boolean
P-2.3	Territoriality, privacy[3,5,6]	BIM, GIS	Boolean
Environmental			
P-2.4	Soil contamination[6,7]	GIS	Nominal
P-2.5	Noise levels[3,4]	GIS	Numeric, specified in dB(A) [f]
Surroundings			
Accessibility			
S-1.1	Distance to nearest railway station[1,4,5,b]	GIS	Numeric, specified as passible distance in meter [f]
S-1.2	Distance to alternative public transit[1,4, b]	GIS	Numeric, specified as passible distance in meter [f]
S-1.3	Distance to highway exit [1,4,5,b]	GIS	Numeric, specified as passible distance in meter [f]
S-1.4	Distance to airport [1,5]	GIS	Numeric, specified in meter [f]
Demographics			
S-2.1	Population density [1,3,e]	GIS, statistics agencies	Numeric, people per square meter [f]
S-2.2	Disposable income [3,6,e]	GIS, statistics agencies	Numeric, specified in local currency [f]
S-2.3	Employment ratio [3,6,e]	GIS, statistics agencies	Numeric, ratio of working population employed [f]
Safety			
S-3.1	Crime rate [1,3,4,6,e]	GIS, statistics agencies	Numeric, number of crimes committed [f]

S-3.2	Distance to police, fire brigade, private security services [3, b]	GIS	Numeric, specified as passible distance in meter [f]
Facilities			
S-4.1	Distance to city center[3,5]	GIS	Numeric, specified as passible distance in meter [f]
S-4.2	Amount of green area [1.3,4,d,e]	GIS	Numeric [f]
S-4.3	Amount of public space [1,3,4,d,e]	GIS	Numeric [f]
S-4.4	Amount of water [1,3,d,e]	GIS	Numeric [f]
S-4.5	Groceries nearby [1,4,e]	GIS	Boolean
S-4.6	Shops nearby [1,5,e]	GIS	Boolean
S-4.7	Restaurants nearby [1,4,5,e]	GIS	Boolean
Clustering			
S-5.1	Competitors nearby [4,5,e]	GIS	Boolean
S-5.2	Supply chain partners nearby	GIS	Boolean
Legal			
S-6.1	Zoning law regulations [3,6,c]	GIS	Nominal

Notes:

1 (Remøy, 2010)

2 (Bottom, McGreal, & Heaney, 1998)

3 (Voordt & Wegen, 2005)

4 (Geraedts & Voort, 2003)

5 (Korteweg, 2002)

6 (Stichting Real Estate Norm Nederland, 1992)

7 (Glumac, 2012)

a Remøy (2010) and Bottom *et al.* (1998) both mention flexibility as an important attribute. We argue that architectural openness is a quantifiable measure that is related to this concept.

b Distance to highway exit and others should be determined whether they are measured 'as the crow flies' or real distance over the earth surface.

c Even though the government is involved with the population of facilities and facilitates the development of the framework, facilities suggested by the framework still need to go through regular application procedure for approval.

d Rather than specifying distance to certain facilities (e.g. water, green area, public space) we use land use maps to aggregate the amount of these facilities in a (500m * 500m area). This provides a more detailed image of the surroundings.

e Demographic, land use related, and crime rate, attributes are measured over an area of 500 by 500 meters. Attributes that are specified as nearby are 500 meters as default.

f Users need to specify whether they need minimum, maximum, or approximate for some or all numeric attributes for fuzziness concern to deal with asymmetric or imprecise requirements.

APPENDIX B SBI CODES RECLASSIFICATION

https://figshare.com/s/d480604ed44e1277f428

APPENDIX C SIMILAR CASES DETAILED INFORMATION

ID	2	11
Case	Drie Hoefijzers	Lichttoren+Victoriapark Eindhoven
Location	Nearby Station Breda	Eindhoven centre
Size (hectares)	8	4.74
Previous use	Industry	Industry
Plan use	Mixed	Business centre, office, housing
Surrounding	A bigger development zone	City centre
Distance to city centre	2.0 km to Breda centre	0.4 km to Eindhoven centre
Distance to transportation	0.3 km to station Breda	0.9 km to station Eindhoven
Legal and political concern	Reduce car mobility, reduce railway barriers, promote public transport	Historical industrial image preservation. A landmark for visitors of the city. Connect and stay high-quality living
Noise	Optimal acoustic design and soundproof features; Exemption given for higher values	The exemption given for higher values
Soil	Yes, three cases to be remediated	Heavy metal contaminated, the action might be needed for some functions
Water	No information	Separate sewerage system
Archaeological	Different depth complies with different regulations/measures	Monumental buildings
Energy usage	Energy neutral	A heat pump system. Renewable energy. Adding proper insulation. Application of heat and cold storage in the ground
Risk	No localized risks from the transport of dangerous substances	Optimize the fire water supply by installing seven additional faucets.
Road design	Westside a new residential street is added	City centre, train station, connection to A2/E25
Bicycle	Improvement of bike and footpath routes	Better accessibility
Parking	New developments provide sufficient parking places.	Parking (276 spaces): 8,000 m^2
Public transport	No action needed	Connection to A2 / E25 to be improved

Finance	Anterior agreement between AM Wonen and the city of Breda, no financial concern	Costs: € 100mil.
Expected outcome	120 houses, some apartments, southern part connects to the city with arrangement of public spaces; northern part separated from southern because of the rail line, needs design to guarantee the quality	live: 16.000 m^2 - Hotel (commercial and social): 15,500 m^2 - Office: 3.650 m^2 - Commercial: 4,250 m^2 - Parking (276 spaces): 8,000 m^2, 128 lofts
Plan history	2007---, Five phases, first phase finish in 2010.	2003-2009
Public involvement	Public consultation meeting	Yes
Stakeholders	The government, water board, Consultant, Contractor, Landowner, Future residents, Housing Corporation, Chamber of Commerce and Industry, etc.	Trudo, Municipality, De Nieuwe CombinatieVastgoedontwikkeling, Deerns Raadgevende Ingenieurs, Stam + de Koning Bouw
Keywords (Visions)	The brewery, Monumental buildings, Historical image, City centre, Industrial image, Sustainable energy, Public participation, Soil sanitation, Quality of life, Acoustic design, Mixed function, Archaeological values, Improve accessibility, Reuse existing buildings, Smooth transition	City center, Industrial image, Historical image, High quality urban environment, Railway, Station, Durability, Sustainability, Flexibility, Mixed function, Reuse existing buildings, Social housing, Expats, Monumental buildings, Green area, Service facility, Office, Improve quality, Livability, Smooth transition, High quality, High-rise buildings, Connection, Stay, Flexibility
population density before per km 2	5343	5555
residents before	1450	990
area size before	27	18
sellable part before	8	4.74
percentage of households with kids before	11%	7%
percentage of the single person before	67%	61%
average kindergarten within 3 kilometres before	20	20.7

population density after	7807	5496
Residents after	2130	1080
area size after	27	18
sellable part after	0	0
percentage of households with kids after	13%	11%
percentage of a single person after	66%	53%
average kindergarten within 3 kilometres after	27.8	25

APPENDIX D SIMILAR CASES ZONING PLANS

https://figshare.com/s/5ce409ebe31458052223a

APPENDIX E INDICATOR CALCULATION ASSUMPTIONS

https://figshare.com/s/9670f14886b2cf957b26

APPENDIX F TARGET SITE ZONING PLAN IN REALITY

https://figshare.com/s/3ca280acb4e68edf1610

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CURRICULUM VITAE

Tong Wang was born on 21-08-1987 in Liaoning, China. She studied Real Estate and City Management at Zhejiang University, China and obtained her B.Sc. in 2010. From 2010 to 2012, she studied Construction Management and Engineering and graduated as a Cum Laude M.Sc. in TU Eindhoven, the Netherlands. She received Talent Student Scholarship for this master study. She won the second price of business plan development in her master time.

After her master study, Tong Wang started as a researcher on sustainable urban redevelopment. She obtained her funding from the China Scholarship Council. The PhD research results are presented in this dissertation. A planning support system is proposed for the sustainable data-driven redevelopment of disused industrial sites. Machine learning and case-based reasoning techniques are applied to reuse prior knowledge. Web tools are developed for public participation. This research is performed in the Information Systems group of the Built Environment in TU Eindhoven.

During this period, she published her work in scientific peer-reviewed journals and presented in multiple international conferences. She had the chance to teach master students in TU Eindhoven about research methods in Construction Management and Engineering.

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