A Sustainability Impact Assessment Model Based on Functional Diversity

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Abstract

In this paper, the development of a Sustainability Impact Assessment Model (SIAM) is presented. This tool is a solution for the demand for a more integrated approach, which analyzes sustainability impacts as a result of (re)arranging urban functions in a densely built-up urban area. The tool combines a calculation method – based on majority additive-ordered weighted average (MA-OWA) – and Analytical Hierarchy Process (AHP). The developed model has the potential to calculate land use sustainability impact based on functional diversity in all directions (horizontal, vertical and diagonal) at three levels (building, location and area), regarding all three pillars (planet, people and profit). The model was tested in a case study project: Europoint Rotterdam located in the Netherlands. The results show that the model is robust in measuring the impact of sustainability of integrated functional land uses, and it can be used as both a measurement and a communication tool.

1. Introduction

It's time for change. Economic, demographic, social and environmental developments have become the drivers for changes in urban development. Exploitation should be based upon continuity and long term value development from now on, allowing real estate and urban areas to grow along with changing demands, resulting in future-proof urban development. The value of real estate and its surroundings will be related to flexibility and sustainable design and its prolonged exploitation. The focus will shift from quantity to quality (Agentschap NL, 2011). Continuity and flexibility are key factors in sustainable urban development. Sustainability will no longer be a distinctive factor, but will be raised to a standard (FGH, 2011).

"*Intricate mingling of different uses in cities is not a form of chaos. On the contrary, they represent a complex and highly developed form of order.*" – Jane Jacobs (1961)

This quote introduces the central theme in this research: functional diversity. Jane Jacobs, an American-Canadian writer and city activist, already advocated for functional diversity back in the sixties. Jacobs argued that it is all about the keen integration of different building types and uses, residential and commercial, old and new, to create urban vitality. The intermingling of city uses and users are critical to economic and urban development according to Jacobs.

Half a century later, Jacobs is finally getting support in this regard. Sustainable development has become a central theme in urban planning all over the world in the recent years. Repositioning functions is considered to contribute to create a more sustainable and future-proof built environment (VROM-Raad 2010). Red (buildings), green (nature) and blue (water) functions should be positioned in such a way that it yields sustainable profit. Interrelationships between land uses should strengthen socio-cultural, economic and ecological values for concerned stakeholders. The values of these stakeholders should be connected in order to create synergy. Smart urban development prevents undesired impacts and establishes connections between stakeholder values in order to create mutual gains (Nirov, 2011).

Several researchers have addressed functional diversity and sustainable development in their studies. The spatial interaction between different urban functions can be either positive or negative depending on the scale (Taleai et al., 2006). The interaction between functions often results in multiple effects in various aspects. Kong et al. (2007) explored the relationship between green spaces and house prices, and confirmed the positive economic impact of proximate urban green spaces on house prices. With the focus only on one specific effect of functional mingling in an urban area, additional externalities of green spaces in urban areas were disregarded, like contribution of urban green spaces to air quality, viability, water regulation and biodiversity. By narrowing down the research to one specific aspect, limiting their scope considerably, undesirable side effects might be overlooked. Green area might have negative influence on the feeling of safety or the social control, for example.

The narrow approach seemed to have the upper hand in scientific research about sustainable urban development. Consequently, a sub-optimal outcome arises as a result of a strong focus on a single sustainable aspect (Ministerie van Infrastructuur en Milieu, 2011). The focus in this narrow approach was often placed on the ecological interest (Nirov, 2011). Re-embedding of the ecological interest to a broader context is needed (VROM-Raad, 2010). A prospective sustainable ecological future is not conceivable without well-balanced socio-economic ratios, which meet up to the sustainable ambitions to the upmost. Ecological and socio-economic interest need to be addressed in relation to each other.

Traditionally, Dutch planning and designing tend to apply narrowed approaches when it comes down to land use allocation in urban development. Nowadays a bigger ambition has emerged: striving for reciprocal gains. This new trend seeks for synergetic urban functional combinations: solution which pursuits economic, ecological and socio-cultural added value. Such an approach aims at linking added value at different levels. However, a systematic analysis of possible synergetic solutions by (re)positioning functions in an urban environment is missing. A more integrated approach is needed which systematically investigates potential added value to a sustainable urban environment as result of (re)arranging urban functions. The challenge is to comprehend the effect of possible function combinations on economic, ecological and socio-cultural values in relation to each other. This research aims at filling this gap and providing a modeling tool which generates insight into the potential sustainable profit as a result of a certain configuration of urban functions in a specific urban context.

In the following section, first we will briefly introduce the concept of sustainable development used in this study and discuss the potential impact of functional diversity in relation with sustainable development. Then we will explain the integrated tool we proposed and use a case study of Europoint Rotterdam area to show the robust performance of our approach. Finally, we will draw some conclusions and provide some recommendations.

2. Sustainable development

The Brundtland commission introduced and defined sustainable development as “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission of Environment and Development, 1987). This definition dates from 1987 but is still widely accepted today.

This definition is rather vague. Hooijmeijer et al. (2001) is one of the researchers who tried to concretize sustainable development by developing a framework in which spatial requirements (utility value, experiential value and future value) interlinked to social, cultural, ecological and economic interest. This is basically a combination of the Triple Bottom Line (Elkington, 1998) and the Vitruvian Triad (firmitas, utilitas, venustas), resulting in a matrix with 12 characteristics for spatial quality.

For measuring sustainable development at area level, several instruments have been developed in order to measure and classify sustainability. The main labels applied in urban development in the Netherlands are BREEAM, LEED and GPR Stedenbouw. Another tool is DPL, which was developed as a communication, ambition and monitor tool to measure and provide insight in the degree of sustainability in an urban area. A comparison of the four instruments provided a clear and complete overview of aspects considered in measuring sustainability in urban development, therewith concretizing the concept of sustainable urban development. This analysis has identified a total of 33 sustainable aspects (fig. 1).

	Planet	People	Profit
Utility Value	**Energy**	**Accessability to Social Services and Recreational facilities**	**Space and Land Usage**
	Material	*Accessability Grenery and water*	**Sustainable Transport**
	Food		
	Water		
	Waste		
	Air		
	Surface Water		
	Soil		
Experiential Value	*Abiotic Structure*	**Social Safety**	*Loval Economic Diversity*
	Ecological Value	*External Safety*	*Local Employment*
		Traffic Safety	*Accessability*
		Noise Nuisance	**Quality Perception Area**
		Smell Nuisance	
		Wind Nuisance	
		Heath Nuisance	
		Light Nuisance	
		Insolation	
		Water Nuisance	
Future Value	*Sustainable Living and Building*	**Area and Identity**	**Flexibility**
		Social Cohesion	*Economic Vitality*

Fig. 1. An overview of sustainable aspects

Incorporating all 33 aspects was unfortunately not possible within the limited timeframe for this study. Some of the aspects that is not highly affected by (re)arranging urban functions will be not incorporated, e.g., water. After consultation with experts, only the most sensitive aspects for functional diversity have been included, resulting in 11 aspects. These aspects are highlighted in figure 1 in black bold color. By measuring impact on each of these aspects, the overall sustainability impact can be determined.

3. Functional diversity impacts regarding sustainability

	Functions	Description	Underlying functions
1	Residential	Diverging types of housing	Single family and multi-family housing
2	Offices	The provision of services commercially while the general public is not or only to a minor degree helped directly.	Offices in all sizes, conference facilities.
3	Companies & Industry	The commercial production and processing of goods and articles. Industry is characterized by a high degree of automation.	Industrial companies, utility companies, SMEs.
4	Retail	The commercial sale, rent and supply of goods to persons who rent or buys these goods for personal use. This refers to various industries including the food industry, the fashion industry and the housing industry.	Supermarkets, butchers, bakeries, fashion stores, garden centres, home interior stores.
5	Catering	The commercial provision of food and beverages which are consumed on the spot. Including, bed & breakfast, disco's and party facilities.	Hotels, Bed & Breakfast, Restaurants, Lunchrooms, Coffee spots.
6	Services	The commercial provision of services while the general public is helped directly. Including banking services, personal services and ICT services.	banking office, hair dressers, beauty salons, internet cafes.
7	Educational	Organisations specialized in transferring knowledge, skills and attitudes according to pre set objectives.	primary schools, secondary schools and universities.
8	Healthcare	The whole of activities aimed at improving the health of people.	hospitals, medical centres and dentists.
9	Cultural & Recreational	Recreation in which relaxation stands for enjoying (whether or not cultural activities passively or participating actively.	museums, theatres, recreational dwellings and day recreation.
10	Sport	Physical activities for fun or for profession.	fitness centres, golf courts, tennis courts and gymnasiums.
11	Agricultural	Growing food in and around cities for both non-commercial and commercial objectives	agricultural greenhouses and kitchen gardens.
12	Urban green areas	Public and private greenery in an urban environment with a viewing and / or use function.	visually dominant tree, a park, a park or a private garden.
13	Water(retention)	Surface water whether or not specially meant for water storage.	canals, ponds, wades.
14	Transportation	Movement of people and goods by rail, road or waterways.	public transport station, public transport, parking lots, parking garages.

Fig. 2. An overview of function groups

Functional diversity exists when an urban area has more than one primary function. Primary functions are those which, in themselves, bring people to a specific place for a specific activity because they are anchorages. Urban planning distinguishes six primary functions: living, working, recreation, nature, water management and transport, which are often referred to as red, green, blue, and grey functions. Secondary functions are those that grow in response to the presence of primary functions, to serve the people the primary functions draw, which including healthcare, culture, education, religion, retailing and food production. Using manuals for composing Dutch land use plans (Gemeente Zeeland, 2007) as a guideline, a mix of 14 function groups (red, green, blue and grey) are used in this study, classifying specific functions in urban development projects (fig. 2).

In Dutch practice of spatial planning, functional diversity is often referred to as functional intermingling, which is defined as the degree to which functions are intertwined. The former Dutch Ministry of Spatial Planning and Environment (VROM) has developed 5-piece typology for urban areas in the Netherlands and it is depicted in table 1.

Table 1. A 5-piece scale of functional intermingling (VROM)

Level of functional intermingling	The number of functions intertwined
Very strong	3-4 functions, mainly primary functions
Strong	2-4functions, several primary and /or secondary functions
Moderate	1 primary function, 2 secondary functions
Weak	1 primary function, 1 secondary functions
Mono-functional	1 primary function

4. Sustainability impact assessment model (SIAM)

For the development of a sustainability impact assessment model (SIAM), two methodologies have been combined: Analytical Hierarchy Process (AHP) and a calculation method – based on majority additive-ordered weighted average (MA-OWA) that is originally developed by Taleai et al. (2007). Four types of input data are required: compatibility matrices, stakeholder values, case data and land use alternatives. In the following sections, more detailed explanation is provided.

4.1. AHP and MA-OWA

AHP is used as multi-criteria decision-making tool (Saaty, 2008). As described in the previous section a total of 11 sustainability aspects have been identified and have to be considered in sustainable urban development. Applying AHP ensures that each of these aspects could be incorporated. AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives. Within the framework of this research, the goal is creating positive sustainable impacts, the criteria are the sustainability aspects and the alternatives are multiple functional arrangements for a specific urban development project. By assessing the sustainability impacts with regard to each of the sustainability aspects and then integrate them to a total score, alternatives can be compared on sustainability impacts at various levels as well as on various aspects. Figure 3 presents a tree structure of such a decision problem, in which the interrelationships are modified from the study of Hooijmeijer, et al. (2001).

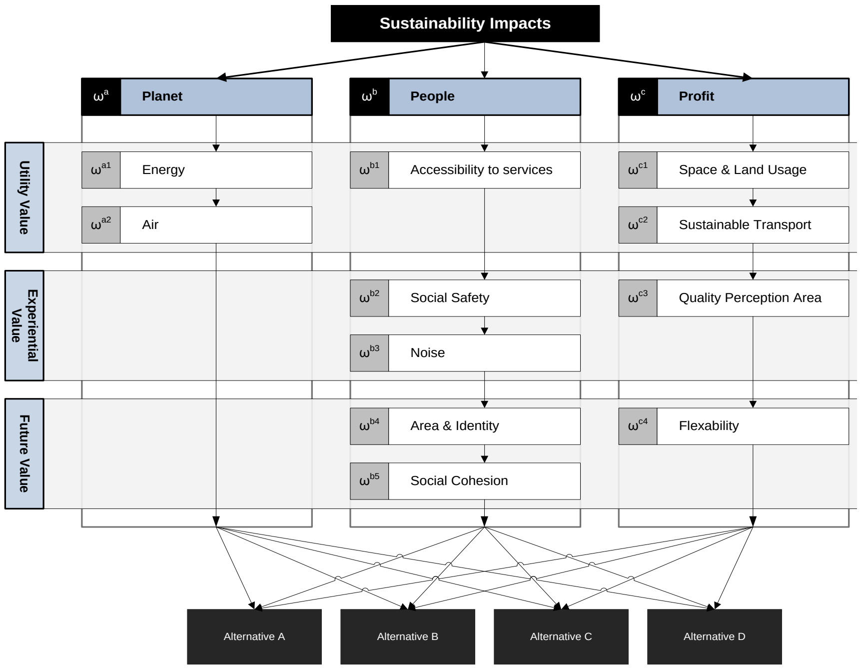


Fig. 3. AHP structure of sustainability aspects

For assessing the impacts in the field of a single sustainability aspect the calculation method – based on majority additive-ordered weighted average (MA-OWA) of Taleai et al. (2007) has been adopted broadly. The Compatibility Evaluation Model (CEM) they proposed has been designed to explore the impacts of spatial externalities among neighboring land uses at a micro-scale. With the focus on negative consequences, the model determines general land use compatibility through measuring potential conflicts among different land use types. In addition to the approach of Taleai et al.

(2007), we propose a more integrated approach, including both positive and negative impacts, for visualizing and analyzing potential sustainability impacts systematically, which will enable users to explore which arrangement of functions optimizes the sustainability impacts in a specific urban context.

Some adjustments were necessary. Aggregation at area level has been added to the approach and the calculation procedure has been adjusted in order to also take into consideration of function combinations in the diagonal direction. The aggregation method utilizes the weight factors in AHP for project specific part taking into account stakeholder values and additive-ordered weighted averaging (MA-OWA) for the general assessment regarding each aspects. The result is an aggregation value that represents the majority and more or less indicates the influence of the minority, thus creating a more precise overall value. This final value indicates to what extent a certain land use configuration potentially generates positive (or negative) sustainability impacts as result of neighboring land uses at building, location and area level.

4.2. Compatibility matrices

The purpose of a compatibility matrix is to assess to what extent every unique function combination is compatible. Compatibility can be defined as the degree to which co-existence of two or more land use types result in positive (or negative) sustainability impacts. In other words, it shows the degree of synergy as a result of functional diversity. These impacts might show effects on multiple scale levels and the magnitude of such impacts might differ for each scale level. The scope of this research is limited to building level, location level and (local) area level.

One sustainability matrix for each of the eleven considered sustainability aspects has been constructed using expert judgments. Instead of using the Delphi method (Taleai et al.2007) for collective opinion, this research relies on individual expert judgments. Decomposing sustainability into eleven aspects enables approaching domain specific experts who are specialized in the field of one single aspect to provide their expertise. The focus on a single aspect is expected to result in sharp and accurate assessment. Eleven experts, all with different backgrounds and expertise, have been approached for assessing the sustainability impact of 105 unique pair-wise function combinations in the field of their expertise. The experts have judged the sustainability impact using a five-point scale, which later converted to a standardized score to be used in the aggregation process (Table

2). The aggregation method is founded on sustainability impact matrices in which sustainability impacts for every possible function combination is depicted.

Table 2. Quantification of compatibility levels using AHP

Compatibility Level	HPI	MPI	NI	MNI	HNI	Geometric mean	Standardized Score
HPI Highly Positive Impact	1	3	5	6	7	3,63	0,53
MPI Moderate Positive Impact	0,33	1	3	4	5	1,82	0,27
NI Neutral Impact	0,20	0,33	1	2	3	0,83	0,12
MNI Moderate Negative Impact	0,17	0,25	0,50	1	2	0,53	0,08
HNI Highly Negative Impact	0,14	0,20	0,33	0,5	1	0,34	0,05

The impact of functional synergy can relate to different scale levels. To what extent the distance between different land uses actually affects the sustainability impact is expected to vary from one sustainability aspect to another. In this study we address three levels: building, location and area level. The same sustainability experts were approached to asses these scale influences. A pair-wise evaluation is conducted by each of the experts. Subsequently, weight factors (eigenvectors) were calculated using analytical hierarchy process (AHP). The final result indicates that the weights differ for each sustainability aspect (table 3).

Table 3. Scale weight factors for each sustainability aspect

	Energy	Air	Accessibility of Services	Social Safety	Noise	Area & Identity	Social Cohesion	Land- and Space Usage	Sustainable Transport	Area Perception	Flexibiliy
Building	0,43	0,20	0,14	0,33	0,64	0,33	0,33	0,65	0,33	0,33	0,64
Location	0,43	0,40	0,43	0,33	0,26	0,33	0,33	0,28	0,33	0,33	0,26
Area	0,14	0,40	0,43	0,33	0,10	0,33	0,33	0,07	0,33	0,33	0,10

The data found in this process is project independent, in other words, these sustainability matrices do not depend on the project characteristics. However, it might reflect the socio-cultural background of the experts. Land use combinations might realize a positive impact for one sustainable aspect and a negative impact for another. Analyses of these matrices have confirmed the enormous potential of functional diversity that is also described in literature. Table 4 gives insight into the most fertile land use combinations by indicating for each land use combination how many positive sustainable aspects can be realized. For example, the number of “6” for the combination of residential and retail indicates that this two specific function combination can potentially have either a moderate or high positive sustainable impact on six out of eleven aspects. The results also show that none of the land use combination creates a positive impact for all eleven sustainable aspects. The combinations with residential land use seem to offer more positive sustainability impacts, while the combinations with companies & industries are relatively incompatible.

Table 4. Matrices analysis of positive impacts

		Residential	Offices	Companies & Industry	Retail	Catering	Services	Educational	Healthcare	Cultural & Recreational	Sport	Agricultural	Urban green areas	Water(retention)	Transportation
1	Residential	7													
2	Offices	7	5												
3	Companies & Industry	3	3	5											
4	Retail	6	2	2	2										
5	Catering	7	6	6	6	3									
6	Services	8	8	2	5	6	1								
7	Educational	7	5	4	2	3	4	3							
8	Healthcare	7	4	1	3	5	5	7	3						
9	Cultural & Recreational	9	5	1	3	8	5	4	4	2					
10	Sport	7	7	1	3	6	2	7	6	6	4				
11	Agricultural	9	6	3	4	5	3	8	6	5	4	2			
12	Urban green areas	8	8	4	4	7	4	6	7	6	7	6	5		
13	Water(retention)	6	5	1	3	6	3	5	5	6	6	5	6	3	
14	Transportation	5	7	6	5	5	5	6	5	4	5	2	3	2	2

4.3. Stakeholder values

Another important input is the stakeholder values. The participation and power of stakeholders in urban development is increasing. Stakeholders will have a decisive role in urban development. Different projects involve different stakeholders with different interests. Incorporating their requirements and values is therefore essential. SIAM foresees in this by enabling involved stakeholders to define a set of weight factors for each of the criteria as illustrated in figure 3 with “ω”. The user of SIAM is expected to retrieve these values from stakeholders by using AHP and pair-wise comparison. Consequently, the output of alternative analysis will be matched to stakeholder values. The values of stakeholders are highly project-dependent and will differ in each project.

In general, the stakeholders involved in urban development can be divided into four categories: government agencies, commercial participants, civil society organizations and citizens. Incorporating each of these stakeholders and merging their diverging values is a challenge in sustainable urban development (Puyleart & Werksma, 2011). The way of matching stakeholder values is a study in itself and is therefore excluded from the scope of this current study. However, the importance of stakeholder participation and values in contemporary urban development is certainly recognized.

4.4. Case data

The third part of the input concerns data related to project characteristics, referring to the functional infill of the urban area. Several steps need to be carried out for catching all the required data regarding the functionalistic arrangement of the case study area.

The first step is to identify all parcels within the project area and to identify all associated land use functions of these parcels by means of a basic parcel map. This data then needs to be structured into a land use table. Land uses for each floor at each parcel in the project area should be joined in the land use table. Sometimes different land uses exist in the same floor. In that case, the floor's use reflects the major land use type found on that specific floor resulting in an abstraction of the actual functional arrangement in horizontal direction on building level. In vertical direction, a different kind of abstracting has been implemented. In vertical direction, land uses will be classified based on the classical division of buildings in a plinth, center section and top layer. A common function division in inner-cities in the Netherlands is a deviating plinth land use (e.g. commercial functions) and residential land uses on top of that. In this study, a basement function has been added to this classical division which enables incorporation of underground functions as well. The detailed way of floor classification is illustrated in fig. 4.

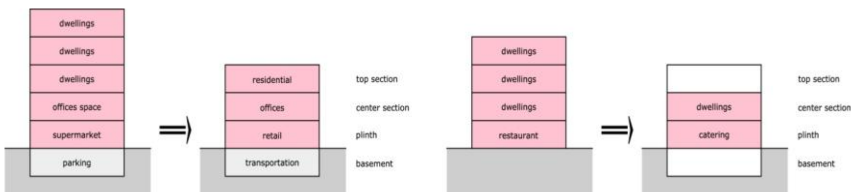


Fig. 4. Floor classification

Next, surrounding land uses need to be classified following the same principle. All land uses in the project area need to be classified using the function classification division presented in fig. 2. Each sub-function will be allocated to one of the main function groups. The resulting thematic function map and the land use table, which could be characterized as an abstraction of the functional urban environment, enables calculation of sustainability impacts based on specific function combinations.

The final step in the process of preparing case study data is defining the scale levels. The scale levels refer to the distance between urban land uses, which will affect the potential sustainability impact as a result of inter linkage of these land uses. In SIAM three levels are distinguished: building level, location level and (local) area level. Building level is directly related to the parcel and is equal to the parcel size. The area level is to be determined by the user of SIAM but a radius of approximately 300 meters around the subject parcel suffices. Finally, by means of a neighborhood assessment the location level for each parcel in the project area is defined. Neighboring parcels are any parcels that are adjacent to or directly opposite or diagonal to the subject parcel which may or may not be contiguous to the subject parcel. Defining these scale levels enables calculation and visualization of sustainability impacts on each of these levels.

4.5. Land use alternatives

The final and main variable is the land use alternatives input. The purpose of SIAM is to analyze and visualize potential sustainability impact as a result of (re)arranging urban land uses. Depending on the target, various land use configuration alternatives can be designed. The current SIAM allows the user to analyze and compare the detailed outcomes up to four land use alternatives, and supports decision making in selecting the best alternative. Furthermore, the analysis will provide the user with essential knowledge about potential sustainability impacts as a result of intermingling specific urban functions.

Following Taleai et al. (2007), the majority additive-ordered weighted averaging (MA-OWA) is used to calculate the sustainability impact value for each floor of each parcel within a delineated urban area at building, location and area level. This process is repeated for each floor, for each parcel and for each sustainable aspect for all the alternatives. Aligned to stakeholder values using AHP, the outputs of SIAM will indicate to what extent the impact of each alternative is at building, location and area level, allowing the user to make a weighed choice for the best alternative. Furthermore, the outputs will enable the user to analyze the outcome thoroughly, providing the user insight about opportunities for a specific project. In the next section, we will use a case study to illustrate how SIAM works.

5. Case study of Europoint Rotterdam

A complex, popularly known as ‘The Peak’ (Dutch: de Punt), is located next to the Marconi-square in western Rotterdam, which are known as the Europoint-buildings (Fig. 5). The complex consists of a building named ‘Overbeekhuis’ (Europoint I) build in 1965 and three office towers of 90 meters high build in the period 1971-1975: Europoint II, III and IV (Wikipedia, 2011). These 22-story buildings, each offering 33.000 square meter of rentable space, are located at the edge of Merwe-Vierhavens, a port area mainly equipped for the transshipment of fruit. However, this is likely to change in the near future as this industrial area will be ‘returned’ to the city of Rotterdam.

a. Europoint II, II and IV **b. The location of the Europoint Towers**

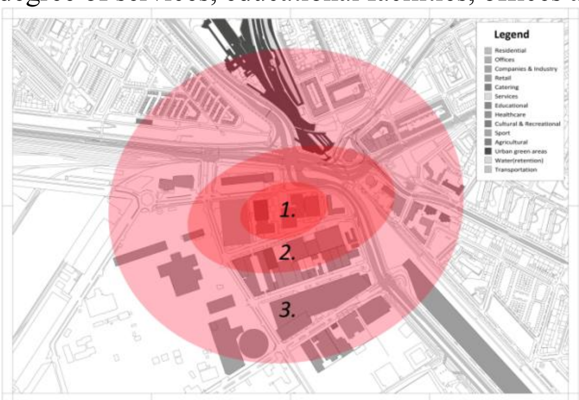
Fig. 5. Case study overview

The Europoint complex is located next to an important public transport junction: Marconi square. The location is encapsulated by an industrial area to the south and three (mainly) residential areas: Witte Dorp, Tussendijk and Spangen. However, the project is separated from these residential areas by the highway S114, which can be characterized as a barrier. To the south-east of the location Dakpark Vierhavenstrip has been realized only recently, which is a huge shopping boulevard with an urban green park on top of it.

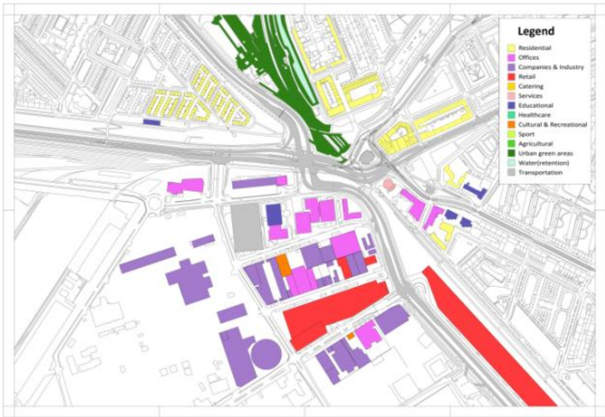
Given the current market conditions, it will be a huge challenge to find new occupants for the vacant 8000 square meters space of these three office buildings. Therefore, all possibilities will have to be considered, including redevelopment to other utilities. The actuality of the task, the scale of the towers, the functional diversity of the neighborhood and the absence of a specified program of demands makes this project the ideal testing ground for SIAM.

5.1. Case study data preparation

In order to calculate the potential sustainability impacts, several project related data inputs are required. First, the project boundary is set by drawing a circle with a radius of approximately 300 meters around the project (fig. 6a). A total of 71 parcels have been identified within this boundary. Next, all land uses of these parcels have been identified and subsequently classified by means of the floors classification and land use classification procedures. The function map in figure 6b illustrates the main functions surrounding the project area. Although located at the edge of an industrial area, not all land uses have been classified as Companies & Industrial, as the industrial area also houses a bar, a nightclub (both catering), some offices and a large retail company. The three residential areas to the north and to east of the project, are mainly residential but also house a certain degree of services, educational facilities, offices and retailing.



a. Neighborhood assessment
(1) project
(2) surrounding
(3) area



b. The existing functional map

Fig. 6. Data of the case study

For testing SIAM using this particular case study, four alternatives for the functional (re)arrangement were composed, which derived from the knowledge gained in compatibility matrices analysis and the functional characteristics of the Europoint area. Each of the alternatives is briefly described below and an overview is depicted in table 5.

Alternative A - 'Business as Usual', in which no land use changes have been implemented, assuming an interested party will be found for letting all the vacant office space. Alternative B - 'Rotterdam Science Complex', which builds on the initiative of creating a science tower with the combination between education and companies & industry. Alternative C - 'Crossing the Barrier', which foresees in a high degree of residential functions. Alternative D - 'Unité d'Habitation', which presents a combination of alternatives A, B and C. This alternative is named after a living complex designed by Le Corbusier which contained internal shopping street and facilities on the roof for its inhabitants.

Table 5. Land use overview for each of the alternatives

		Business as Usual	Science Complex	Crossing Barrier	Unité d'Habitation
Location	Level	Alternative A	Alternative B	Alternative C	Alternative D
Europoint II - high rise	Plinth	Offices	Educational	Residentual	Catering
	Center Section	Offices	Offices	Residentual	Residentual
	Top Section	Offices	Offices	Residentual	Residentual
Europoint III - low rise	Plinth	Offices	Offices	Services	Urban Green
Europoint III - high rise	Plinth	Offices	Healthcare	Residentual	Residentual
	Center Section	Offices	Healthcare	Residentual	Residentual
	Top Section	Offices	Offices	Residentual	Agricultural
Europoint IV - low rise	Plinth	Offices	Catering	Urban Green Area	Retail
Europoint IV - high rise	Plinth	Educational	Educational	Residentual	Education
	Center Section	Offices	Educational	Residentual	Offices
	Top Section	Offices	Offices	Residentual	Sport

5.2. Case study results

After simulating all alternatives a comparison can be made and the best alternative can be selected. For the current simulations each of the aspects are assumed to have equal weight factors. Detailed investigation can be carried out at building, location and area level, for the overall impact as well as for each single aspect. Figure 7 presents the average sustainability impact values at overall project level on 11 aspects. These values indicate to what extent sustainability impact can be realized as a result of a certain functional (re)arrangement which obviously differs in each alternative.

The generated outputs shown that Alternative D has the highest sustainability impact value, which designates alternative D as the best alternative. As expected that a balanced mix of urban land use results in relatively high sustainability impacts by trying to connect to neighboring land uses in all direction. However, the radar graph indicates that alternative D is not superior for all the sustainability aspects. Especially in the field of energy other alternatives score higher. Regarding flexibility and social safety alternative C is better. The PPP and Vitruvian graph on the right side of figure 7 also show some noticeable differences among the four alternatives.

	Sustainability aspects											
	Energy	Air	Accessibility to services	Social safety	Noise nuisance	Are and identity	Social cohesion	Space and land usage	Sustainable transport	Quality perception	flexibility	Average compatibility value
Alternative A	0.28	0.10	0.14	0.12	0.11	0.20	0.17	0.15	0.20	0.10	0.28	0.17
Alternative B	0.23	0.11	0.16	0.17	0.10	0.22	0.17	0.25	0.22	0.15	0.35	0.19
Alternative C	0.14	0.11	0.16	0.24	0.12	0.16	0.16	0.16	0.23	0.16	0.44	0.18
Alternative D	0.17	0.14	0.21	0.19	0.10	0.21	0.19	0.31	0.30	0.21	0.40	0.21

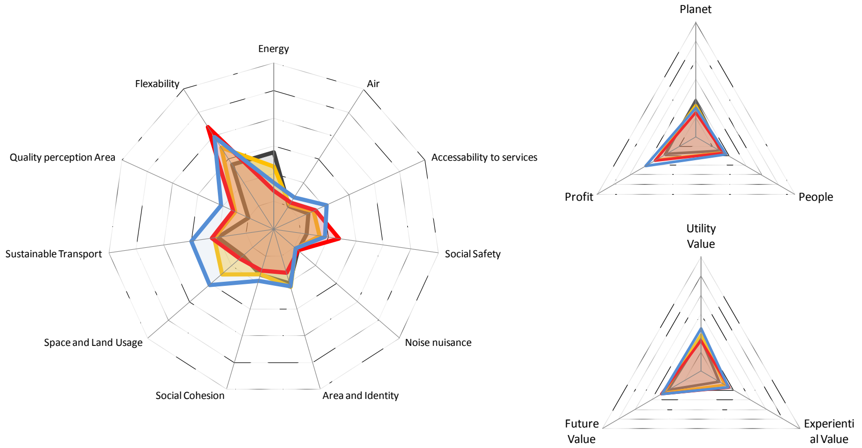


Fig. 7. Alternative comparison at overall project level

Moreover, sensitivity analysis confirmed that stakeholder values have important influences on the results. For example, instead of using equal weigh factors for all aspects, when we put higher weights on social safety and flexibility aspects, then alternative C becomes the best performer. These exercise shown that stakeholders' can reflect their interests and values by assigning different weight factors to the sustainable aspects. As a result, involved stakeholders can also use this tool to communicate and compare in order to get an optimum outcome.

6. Conclusions and discussions

The paper has presented the development of a sustainability impact assessment model (SIAM), which systematically analyses the potential sustainability impacts as a result of a (re)arrangement of urban land uses in a densely built-up urban area. Decomposition of sustainability impact into multiple aspects enables the detailed analysis. Calculating and visualizing sustainability impact for each of the individual aspects at three different levels allows the user to analyze the effect of functional intermingling systematically.

SIAM has been tested by means of a case study. The results have shown that functional diversity not necessarily results in positive sustainable impacts. The potential sustainability impacts might be restricted and in some case reinforced by local characteristics. The compatible matrices analysis is helpful in finding the right land use combinations, which could potentially result in positive impacts. As a challenge to combine land uses which together create a synergetic solution, it is essential to interact with land uses 'offered' by the surroundings of the project. Only when acted on those context opportunities optimum sustainability impacts can be realized.

SIAM can be used as both a measurement tool and a communication tool. Potential impacts can be communicated using visualization and graphs produced in SIAM to all concerned stakeholders. The results of alternative analysis in SIAM may give rise to approach certain stakeholders. SIAM will then come in handy as a communication tool to present the sustainability potentials of the specific land use configurations.

7. Recommendations

These are some recommendations regarding improving the quality and reliability of SIAM. For constructing the sustainability matrices – which form the foundations of SIAM – only one expert has been approached for each sustainability aspect in this study. This was a conscious choice made for manageability purposes. Although several measures have been taken to ensure the quality of these data inputs, it would be better to involve multiple experts for each individual sustainability aspect in order to enhance the reliability of this important data.

Second, combinations of the broadly defined land use categories were sometimes made it difficult to assess the impact according to some of the experts. Educational land uses, for instance, could refer to a small elementary school or a huge university. This difference obviously might affect the assessment of impacts as a result of certain functional combinations with educational land use. Decomposing the broadly defined land use categories into smaller specified land use categories might sharpen the assessments of experts, thus sharpen the output of SIAM.

Third, the number of sustainability aspects considered in this research was limited to 11. These were selected after consultation with experts as the most sensitive aspects for functional diversity. However, increasing this number may result in more precise outputs, thus giving a better indication of potential sustainability impacts. It will not be necessary to incorporate all 33 aspects since some of them are not affected by urban land use combinations, like wind for instance. However, it is conceivable to increase the number of considered aspects in order to sharpen the outcomes of SIAM.

Furthermore, many stakeholders are involved in urban development project usually with diverging values. In order to incorporate stakeholder values better in SIAM, it might be interesting to do some additional research about how to make collective decisions. It would also be interesting to connect SIAM to Geographical Information Systems (GIS) that might simplify the processing of project data with higher precision.

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