Combining GIS and BIM for facility reuse
A profiling approach

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Abstract

Lingering vacant facilities deteriorate the condition of an urban environment, and, as a consequence, actuate neighboring companies to leave the area as well. In addition, new development efforts keep depleting scarce land resources. In this paper, a framework is presented to match existing vacant facilities to the requirements of potential customers or owners to promote sustainable redevelopment and reuse. Important attributes for facility reuse are identified from literature. To automatically extract these attributes from models and their surroundings, Geospatial information and Building Information Models (BIM) are combined. In the proposed framework, a profile is created for each existing vacant facility by combining BIM and GIS attributes. As a result, these profiles can be matched to the desired BIM model, which the aspiring users have provided, based on a weighted distance calculation. The framework presents the most suitable vacant facilities to the users in order to promote facility reuse. These facility reuse alternatives are evaluated based on a single monetary metric that represents the effort required to partially or fully accommodate the requirements of the aspiring users, which is reflected in the weighted distance between profiles from existing vacant facilities and the facility desired by the end-user. This framework identifies suitable areas for redevelopment after which a process is started that forms an iterative and comprehensive evaluation dialog between demand and supply parties, on multiple scale levels, including various design alternatives to adapt the existing facility to the desires of the consumer and revitalize the surroundings according to Geodesign principles. A proof-of-concept of the framework is presented together with the conceptual system structure. Evaluation of the attributes and the technical implementation of their extraction from BIM and GIS data show the technical feasibility of the approach.

KEYWORDS

Facility reuse; Geodesign; GIS & BIM integration; BIM

1. INTRODUCTION

1.1 Problem statement

Unlike regular urban development planning, industrial area development is mainly led and directed on the level of individual municipalities in the Netherlands, with the lack of participation of private real estate investors. The unrealism in new industrial area demand estimation, financial profitability of developing new industrial areas and mutual competition among municipalities all lead to the redundantly large supply of very cheap industrial area land plots (Blokhuis, 2010). As a result, a large amount of existing industrial areas are obsolete, with many abandoned facilities. According to the Dutch national industrial area database IBIS, 1052 industrial areas contain signs of obsolescence, equalling 32,230 gross hectares on January 1st, 2013 (Ministerie van Infrastructuur en Milieu (Ministry of Infrastructure and Environment), 2013). On the contrary, the Netherlands is well-known as a densely populated country, where land resources are scarce. Therefore, industrial area redevelopment and facility reuse are essential, as it can promote regional economies while using resources more efficiently.

In the industrial sector, land and facility reuse is not widespread. A lack of knowledge exists on vacant facilities and their potential for meeting the requirements of aspiring future users. Hence, new facilities are built while instead existing ones could have been reused. Reusing existing facilities is a more sustainable way for reducing the amount of disused, neglected and abandoned facilities and construction efforts.

For a sustainable future, facility reuse needs to be put on the agenda. It can serve as a main driver for land use redevelopment and suitable reuse strategies can democratize the planning process, which would allow private parties to participate and state their interest in a certain facility and its surroundings. Besides these advantages, the facility locations in many cases are historical sites, which are located centrally in large cities. Due to the spatial development of a given area, these buildings can often be heritage-listed and carry the character of a specific time period. This can be attractive to certain types of customers as it provides a sense of identity. From a financial point of view, it is claimed that reusing existing facilities saves 10%-12% investment over building new ones (Shipley, Utz, & Parsons, 2006).

Despite of the aforementioned points, land use planners tend to focus on a larger scale with a top-down perspective when dealing with industrial area redevelopment. On such a scale, details about individual facilities easily get lost, as information about this is not easily accessible.

Recently, more and more detailed building information models get available, due to technological advances as well as legislation required to get building permits. Incentives are thriving in countries like Singapore (Das, Leng, Lee, & Kiat, 2011) and South Korea (Zeiss, 2014). The availability of these models for detailed information about existing facilities enables new methods to stimulate facility reuse.

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 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 are needed at various stages of FM are captured. In addition, GIS analysis can help to find a suitable location for a new facility (Abudeif, Abdel Moneim, & Farrag, 2015; Panichelli & Gnansounou, 2008; Rikalovic, Cosic, & Lazarevic, 2014; Zhang, Johnson, & Sutherland, 2011). However, the implementation level of BIM within existing buildings is limited (Volk, Stengel, & Schultmann, 2014) which can be attributed to the fact that only recently BIM technology has become more popular. Notable exceptions include attempts to integrate BIM and GIS for emergency response and lifecycle management of a facility and its surroundings (Mignard & Nicolle, 2014; Shen, Hao, & Xue, 2012). However, research on BIM or GIS or their integration is limited within the scope of facility reuse. 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 possibility of existing vacant facilities.

1.2 Scopes and assumptions

For facility reuse, the emphasis not only lies on the physical facilities themselves but also on the surroundings. In this article it is assumed that successful selection of a facility for reuse is more likely when geospatial information and building information are both considered. In this way, an entire overview of how one facility functions in its social, geographic and demographic context can be constructed out of regional characteristics, building and encompassing plot attributes. In the scope of this article, a facility is considered to be a commercial or institutional building and its surrounding plot of land. And in one region, there are enough vacant facilities for reuse.

In this research, four general types of reuse are identified for an existing vacant facility, namely: occupying the existing facility only partially, occupying it entirely, using the encompassing plot for additional developments and, lastly, rebuilding another facility after demolishing the original (Figure 1). The natural resources that have been put into the building itself, makes the building the primary objective for reuse. Hence, the redevelopment process as outlined in this framework strives to accommodate facility reuse in the second category: completely occupying an existing facility. One could argue that searching for other existing facilities that match the demand of the aspiring owner more closely can fulfill the objectives behind the other three types of reuse.

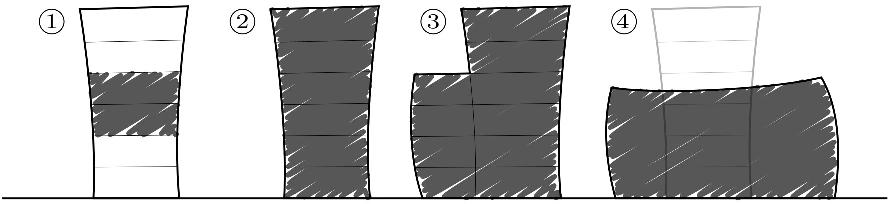


Figure 1. Four types of facility reuse.

1.3 Geodesign for better facility reuse

Facility reuse requires creative thinking and an integrated mindset of considering design alternatives for a building in conjunction with its surroundings. As such, it could benefit from principles outlined in the Geodesign methodology. Geodesign, as Flaxman has proposed and Ervin has amended, is a design and planning method which tightly couples the creation of design proposals with impact simulations, informed by geographic contexts, systems thinking and digital technology (Steinitz, 2012). It is the process of designing in a geospatial environment. Design assignments based on the Geodesign concept are performed globally (McElvaney, 2012). An example in an industrial context is the R2G project, which covers the transition of red fields into green fields, or change of abandoned and possibility contaminated areas into thriving public parks (McElvaney, 2012). In these cases, Geodesign processes and techniques helped to break down large and complex problems into components that could be analyzed. Furthermore, the Geodesign concept and techniques can be used to contribute to a more competitive and user-orientated decision process, which can attract investment and stimulate regional sustainable development.

In order to guide this process systematically, Steinitz has proposed a practical framework based on empirical research (Steinitz, 2012). This framework guides stakeholders by iteratively posing questions about the problem, the area, the process, the assessment results, and consequently creating more informed designs. Hence these guidelines are relevant in the context of facility reuse. After all, in order to understand the mechanisms behind its abandonment, the facility and its surroundings should be described along with the factors that drive changes on a geographical level. Furthermore, iterative thinking and the evaluation of design alternatives are of vital importance to successful reuse strategies.

However, Geodesign is still mainly discussed solely in a geospatial context. No specific attention has been given to incorporate building level information. For facility reuse the building level characteristics are essential to include in the design process. By combining GIS and BIM information, a better design can be obtained to satisfy stakeholder requirements.

In this way, Geodesign can be an instrumental tool for planners and facility owners, and can also gain a better understanding of the inner environment of the facility, its site and location within its broader spatial and social context.

In addition to the established Geodesign methodology, which starts with a specific project area in need of analysis and design, governments could adapt their Geodesign procedures by stimulating potential future users first to identify an area of suitable vacant facilities with the combination of GIS and BIM information. In this way, a collaborative design process, in which the most suitable project area or facility is not always known in advance, can be initiated, and the output of the framework proposed in this paper identifies areas to redevelop.

In addition, the framework proposes a singular monetary metric based evaluation method for different design proposal evaluations, which complies with the evaluation guideline of Geodesign process proposed by Steinitz (2012).

To conclude, the Geodesign framework and tools help to understand the facility and its surrounding, evaluate possible results for various design proposals and negotiate among stakeholders for a better final design. The proposed method provides a starting point for finding suitable facilities for further analysis and a simple evaluation paradigm for design proposals.

1.4 Objectives

As discussed in the problem statement, facility reuse is of great potential for sustainable development. In this chapter, a framework is proposed that enables public parties to accommodate facility reuse by private parties. It enables aspiring facility owners to match their criteria with characteristics of existing vacant facilities and discover those that are most suitable for redevelopment or reuse. A literature study has been conducted to find the most influential attributes for facility reuse and their data sources. In order to obtain such a system, data sources from both BIM and GIS are aggregated to provide stakeholders with a comprehensive overview of the facility and its geographical context. To aggregate different data sources, commonly used formats of GIS science and BIM are reviewed and possible integration methods are proposed. After data integration, a weighted distance calculation is applied, based on various attribute differences between the desired facility and existing vacant facilities. Aspiring owners can select a facility, based on a single monetary metric that is composed of the acquisition costs, and a monetary interpretation of the extent to which the existing facility might not meet all criteria set by the end-user. It is this single monetary metric that guides the evaluation of different facilities. Likewise, options for adapting the existing facility to meet all requirements can be evaluated iteratively. Guidelines from the Geodesign concept steer the conceptualization of the requirements. The effort is mainly directed at industrial facility reuse for promoting a regional sustainable redevelopment process to use resources more efficiently and provide economically more viable and desirable facilities to its users. Data sources and data integration are discussed. Several tools have been identified to extract attribute values from various heterogeneous data sources. However, an implementation and evaluation using real stakeholder data is beyond the scope of this paper.

In the following sections, a theoretical background for integrating GIS and BIM are presented and the framework and its proof-of-concept implementation are discussed. The technical implementation of the extractions shows the viability of the approach.

2. THEORETICAL BACKGROUND

2.1 GIS and BIM data formats

The Industry Foundation Classes (IFC) file format is a commonly used standard in the domain of BIM. It is spearheaded by the buildingSMART consortium and has been ratified as an ISO standard. 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 and has an EXPRESS schema definition, which defines the entities along their attributes and relationships that constitute a valid IFC file. IFC files are stored as either ASCII or XML 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 for describing building models exist, for example gbXML , or proprietary file formats which are native to commercial BIM applications. The former is primarily intended for use within sustainability analysis and is therefore not considered for inclusion into the system. Proprietary file formats, for which automated tools to extract data are not available, are not considered either as they would hamper the development of the system.

Conversely, in the GIS domain, shapefiles are a commonly used option for describing vector features. Rather than led by an industry wide consortium, 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 over 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 semantics to these features. Overlap between, and ways to interlink, the different data carriers can be found on the building and site level, where GIS features describe the same building or site in a BIM model.

An IFC file has a default decomposition structure, which starts with a project and descends into a site, a building, individual building stories, 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. Attributes can be applied to the polygonal boundary, such as the building height or the functional characteristics of the building it refers to. 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 in the cadastral records. The IFC standard primarily intends the site to be used for documenting the construction site. As defined by the IFC standard, a site does have an optional definition of a single geographic reference point, specified by its latitude, longitude and elevation. This is a key factor for being able to link a building model to a feature in a GIS database, as string-based building identifiers are error prone and context specific.

In addition, hybrid formats intended for use on an intermediate scale exist. For example, the CityGML format , which is an XML based standard led by the OGC . 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 considered for this prototype, as public datasets on an urban scale are not available within this project.

2.2 Combining versus converting

Despite the differences in how data are stored in the GIS and BIM domain, the attributes that are relevant for this prototype system implementation can be extracted into a uniform tabular structure of attributes. This method is different from other strategies found in the literature, for example on building an integrated system by converting one format into the other. The translation from IFC to CityGML is discussed in (Isikdag & Zlatanova, 2009; Nagel, Stadler, & Kolbe, 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 and mapping 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. As such, in this paper, we combine GIS and BIM data sources for the purpose of facility reuse without the associated loss of information of converting data formats.

2.3 Guidelines for integration

The presented 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. 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 information loss.

On the other hand, 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 the framework. 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 georeferenced point. In this way, 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 important 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 needs to be done manually in a graphical user interface.

In general the extracted information from the GIS and BIM domain may need to be curated upon ingesting the information into the system.

3. IMPLEMENTATION

3.1 Framework

The framework 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 framework then composes a vector of quantitative measures that describes 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, within this framework, 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 demand 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 framework 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.

3.2 Attribute identification

A list of prominent attributes for facility reuse is identified and presented in Appendix A. They are categorized into building-level attributes, building plot and geospatial characteristics and demographic properties. The identification of the attributes is based on a literature review (Bottom, McGreal, & Heaney, 1998; Geraedts & Van der Voordt, 2003; Glumac, 2012; Korteweg, 2002; Remøy, 2010; Stichting Real Estate Norm Nederland, 1992; Van der Voordt & Van Wegen, 2005).

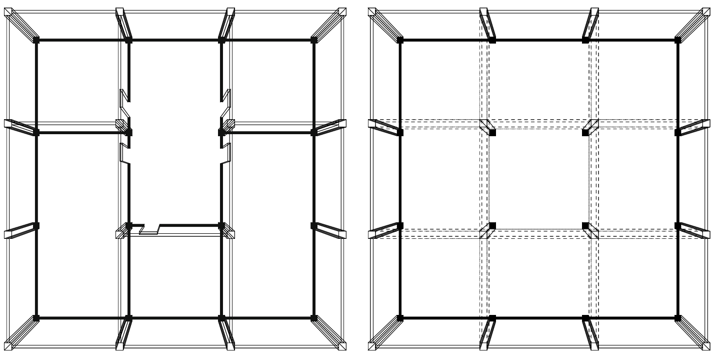


Figure 2. An illustration of the openness of an architectural space, quantifiable by dividing the volume of spatial separation elements (such as walls, columns and beams) by the volume of the spaces itself, to be extracted from the BIM. The architectural openness can be seen as a measure for the flexibility of the facility.

Figure 2 illustrates one of these attributes for two distinct facilities. The objective is that all attributes are unambiguously quantifiable and extracted automatically without user interpretation from the building model or geospatial and statistical information sources. Additionally, attributes are classified according to their level of measurement, whether they are numeric or nominal. 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 this area.

3.3 Distance calculation

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. Key distinguishing attributes can be represented as an axis in an overview to the user. In such way the user can initiate an interactive negotiation process in which the set of vacant facilities is explored. A graphical depiction of this overview is presented in Figure 3.

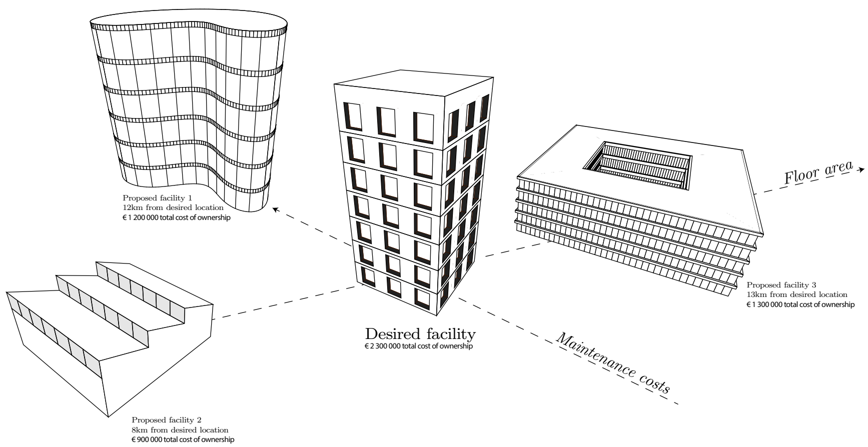


Figure 3. A schematic representation of the facility selection process in which several axes, representing the attributes at which the facilities differ, are presented to the user together with the renovation costs.

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 indicators is assigned with a weight _i according to the stakeholder evaluation. 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. This will be explained in the next section.

3.4 Fuzzy theory

Suppose the client requires a minimal ceiling height of 4 m 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 4.5 m is as preferable as 3.5 m. This is clearly not the case, as the latter violates the regulations. As a second example, suppose the client suggests a minimal floor area of 40 000 sq.m. Surely some tolerance is desirable, so that a facility of 39 800 sq.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 simply be a constant f_i (x)=1. Figure 4 illustrates a possible fuzziness function for the ceiling height example, where is the standard deviation of the existing vacant facility attributes' values. As the normalized difference approaches – the weighted distance will approach infinity, rendering this facility unsuitable for selection due to the large distance, whereas when the requirement is met, the function trends towards zero, diminishing the weighted distance.

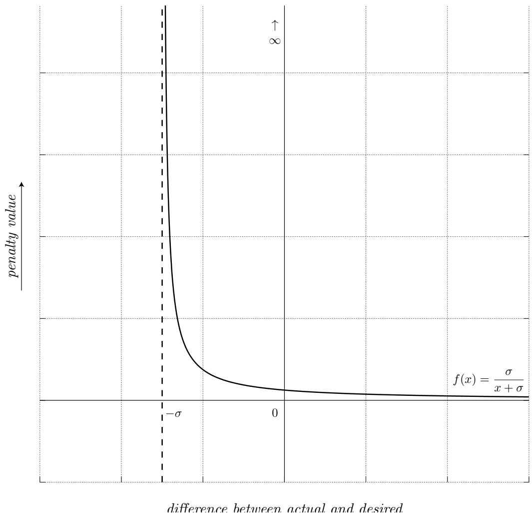


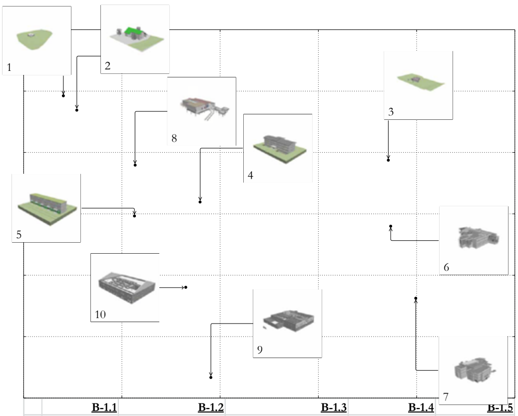
Figure 4. A possible fuzziness function for a minimum value attribute.

3.5 Monetary based negotiation

As discussed in the previous section, some attribute requirements might not be fulfilled completely by means of the selection process. It is important to realize that the method presented in this paper 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 4, it is easy to see that by architectural remodelling the two spaces can be made more equivalent, a transformation that comes with a monetary 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 monetary 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 with the projected costs for establishing a newly built facility by means of a unified monetary measure.

3.6 Proof-of-concept

In order to prove the concept of our system, Dutch data sources are explored to give insights to future users where to obtain data (See Appendix A). Since GIS is commonly used in the field of Geodesign, calculating and extracting data from ArcMap is not discussed here.



	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 5. A demonstration of automatically extracting attributes from IFC building information models.

In order to demonstrate the feasibility of automatically extracting attributes from IFC building information models, a list of such attributes is presented for a selection of publicly available IFC models . A graphical interpretation of this data is shown as well (Figure 5). This plot uses a multi-dimensional scaling algorithm that tries to preserve relative distances of the samples while embedding their multi-dimensional space into the rendered two-dimensional plane. As such, similar buildings are presented close to each other. Attributes pertaining to building areas are either to be found in IfcPropertySets on an IfcBuilding level, or if absent, aggregated over the various IfcSpaces in the model. Ceiling height and building height are deduced from the Elevations of the IfcBuildingStoreys. Architectural openness is computed from the solid volumes of the IfcRepresentationItems of IfcSpaces and IfcWalls, which are computed by an open source software toolkit for IFC files, called IfcOpenShell . With the attributes extracted from the confluence of GIS and BIM, they can be incorporated into the proposed system for selection by end-users.

Figure 6. A screenshot of the proposed framework outlining the steps involved of using the system.

Figure 6 shows a screenshot of a proof-of-concept implementation of the system discussed in this article. It outlines the procedure that the end-user will follow when using the system to get suggested facilities based on a digital building model of his required facility.

At the first step, the potential users are asked to upload their desired facility BIM model to the system so that several of the attribute values can be automatically extracted by the system. In case no building model is available, the user can complete the list of attributes manually. If the building model is georeferenced, geospatial and demographic information is extracted from the GIS seamlessly, otherwise a geolocation needs to be specified by the user to guide the same process.

Secondly, the user can apply weights to these identified attributes and curate the extracted values where necessary. The user is able to indicate whether these values signify minimum, maximum or approximate values, which is reflected in the weighting function explained above.

Based on the combined attributes extracted from BIM and GIS, the system composes the demand profile and calculates the distance with each of the available vacant facilities by applying the formula outlined above. The most similar vacant facilities are presented. The vacant facility information is provided by the supply party of industrial facilities. This includes building information models and geospatial characteristics. Even though policy makers realize the importance of building information models, there is are not many publicly available BIM models.

Conclusively, in an iterative design process the user can evaluate the attributes once more by assessing their impacts on the projected expenses of acquiring the facility and adapting it to match the initial requirements. Note that not only costs associated to the building itself are estimated, but differences in the geospatial attributes are reflected in the evaluation as well, as they represent risks associated with the demographic and spatial characteristics of the target area.

4. DISCUSSION AND CONCLUSIONS

Facing a severe vacancy of industrial facilities, a challenge is evident to solve negligent depletion of land resources. In this paper, a framework is presented to match existing vacant facilities to the requirements of potential customers to promote sustainable redevelopment with possible private investors involved. The concept of Geodesign acts as a framework for iterative evaluation on multiple scale levels and can be formally initiated after stakeholders have used the proposed framework to identify an area for redevelopment. In order to facilitate the evaluation of attributes that have an asymmetric nature, the framework applies concepts from fuzzy theory. In addition, a simple straightforward monetary based evaluation paradigm is presented for the purpose of facility reuse. The proposed framework complements the set of tools that concurrently Geodesign professionals have at their disposal.

To conceptualize this framework, a literature study has been conducted to identify important attributes for facility reuse, both on building level and on regional level. In this way, geospatial information and building information can be seamlessly combined. These attributes are classified based on their scale, source and type. For integrating geospatial information and building information, a theoretical background is illustrated considering data formats, integration possibilities and the preferred way of integration by extracting relevant attributes without interoperability problems. In the appendix, possible data sources and ways to extract or calculate attribute values for Dutch cases are presented. The implementation of extraction proves the feasibility of the approach suggested in this paper.

The framework is designed to provide a comprehensive and effective way to stimulate facility reuse. The methodology outlined in this paper is of a general nature and relevant to various situations. Nevertheless, several aspects are still to be addressed in future research.The way to determine vacancy of a facility varies based on local situations and regulations. It can be estimated by means of employment rate or the usage percentage of floor area, but general unified measures of required detail are not always present. Thus, a pre-consultation with supply parties is essential.

In general, at this moment, implementing this framework on a global scale is not feasible due to the fragmentation of data sources and regulations. This is not necessarily detrimental for a further investigation of this concept, as aspiring owners of facilities are likely to have a clear target location in mind to house their facility before consulting this system. 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 are 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 supply parties and local governments to acquire the necessary data.

Moreover, the Geodesign concept helps in understanding the facilities and their incorporation in their social and geographic context. Following this methodology, the facilities are not isolated from the environment and alternatives are evaluated based on the importance that stakeholders have defined not only on a building level, but also pertaining to the building plot and its geospatial relations. In addition to the monetary evaluation, a more visual representation of the difference in attributes can be presented, based on future research that might appeal more to people with a design background. As have been illustrated, the framework not only initiates the Geodesign process by providing possible facilities for reuse, but also provides guidelines for further iterative evaluation and assessment of various reuse designs in a geospatial environment. Though current evaluation is solely monetary-based, further research can be performed for more holistic evaluation according to future user requirements.

As discussed in the section on data acquisition, common guidelines about BIM and GIS data interoperability can be provided to the future stakeholders so that systems such as these, that build on a combination of the two sources of information, but also other efforts related to BIM and GIS harmonization, can flourish.

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