

# How can development plans promote the sustainability of construction projects?

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**Abstract:** The increasing demands on sustainability require a reorientation in neighborhood and building planning that takes into account various criteria from different areas. Early planning decisions in particular have a significant influence on the later sustainability performance of construction projects. Development plans are a suitable instrument for considering and ultimately defining tangible sustainability requirements for future neighborhood quarters and buildings at municipal level. A multi-layered model-based approach was developed for this purpose, which can be seen as a link between municipal neighborhood development and the subsequent building planning. Based on identified development plan parameters, a two-stage semi-automated process is used to perform a multi-criteria (ecological, economic and social) sustainability assessment. Initially, the parametric building envelope is generated based on the assumed development plans boundary conditions. In the second step, this is linked with component assemblies, materials, social, cost and environmental parameters. This process is repeated for various compliant scenarios and the results are then compared to determine the Pareto optimum for various criteria. In this way, the potential of the sustainability requirements defined in development plans can be clarified and the influence of early consideration and comparison of different scenarios for municipal urban and neighborhood development can be demonstrated. Advancing standardization (system, management and technical standards) and digitalization (data availability) in the field of neighbourhood planning and development will allow the potential to be further exploited in the future.

**Keywords:** Building information modeling (BIM), design automation, algorithms, energy simulation



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## 1 Introduction and research framework

The realization of construction projects requires highly demanded primary resources and consumes huge amounts of energy. In addition, especially the extraction of raw materials and the manufacturing of construction products have a considerable impact on the environment [1].

Because of this, various goals have been defined that increase sustainability and thus should lead to a more circular economy. The main goals are to reduce the use of primary raw materials, close

material cycles, increase durability and reuse and exploit the potential of digital technologies such as BIM [2]. In order to implement this, it is necessary to identify the relevant levers (laws, guidelines and planning tools) for demanding and promoting greater sustainability and to provide construction-related information in a transparent, structured form to enable the use of standardized methods for calculating sustainability metrics.

The municipality can play an essential role in the solution here, as it is the planner and decision-maker in the creation and adaptation of land use planning and the subsequent planning and implementation of specific construction measures [3]. Municipal decision-makers have the opportunity to define various boundary conditions in context of sustainability for a construction project through the tendering process and land use planning. In Germany, the development plan in particular offers the opportunity to integrate sustainability aspects in a legally binding manner at an early stage.

With this area in mind, the characteristics of the development plan and the benefits of early BIM application are first presented before existing approaches in the context of sustainability calculation and optimization are outlined. Based on this, the developed optimization approach is introduced step by step and evaluated and finally classified using an implementation example.

### **1.1 Development plan and early BIM**

Development (de: Bebauungsplan (BPlan)) and land use (de: Flächennutzungsplan) plans are an essential tool of urban land use planning. The land use plan is serving as a preparatory guide for the land usage of a municipality and the development plan as a binding urban instrument, that controls land use and urban development within specific areas of the municipality. According to the German Building Code (de: Baugesetzbuch), the development plan consists of two parts: the plan drawing, which graphically depicts the spatial arrangement and use of the land, and the text description, which describes the stipulations in detail. The objectives of the development plan are to ensure orderly urban development, sustainable land use and the creation of a legal basis for construction projects. However, the creation or adaptation of development plans is a time-consuming and complex procedure and can sometimes take several years.

Digitalization, particularly through the use of Building Information Modeling (BIM), significantly enhances the effectiveness and quality of building planning and construction processes. It facilitates early project evaluation, minimizes errors, and enables the pre-calculation of costs, environmental impacts and other aspects [4]. As part of linking the development plan and early planning phases with the help of BIM, the approach of Emamgholian et al. illustrate how development plan requirements can be integrated into the 3D environment in the form of rule validation and approval control. In addition, Borkowski et al. demonstrate that different environmental (GIS) and building information (BIM) can be merged and introduce the LIM (Land Information Model) for this purpose [5], [6].

### **1.2 Multi-criteria sustainability assessment**

A sustainability assessment system typically involves data gathering, impact assessment for decision-making, and preparation for monitoring and reporting. It relies on established standards, iterative data refinement, and standardized procedures, with regulations being crucial for effective implementation [3]. The underlying environmental sustainability assessment method is the four-step (goal definition,

life cycle inventory, life cycle impact assessment and evaluation) LCA (life cycle assessment), which is standardised according to ISO 14040/44 [7], [8]. The LCC (life cycle cost assessment) and SLCA (social life cycle assessment) assessment follow a similar pattern to LCA and can be aggregated to the overall LCSA (life cycle sustainability assessment). In the context of LCSA, Wortmann et al. demonstrate that both the selection of materials (micro) and the urban or neighborhood morphology (macro) influence the various environmental impact directly [9]. It can be stated that for an object (material to urban scale) with the greatest possible sustainability, elements of micro, meso (building) and macro levels should be taken into account.

A current notable challenge within LCSA involves inconsistent utilization and insufficient clarity concerning the underlying data and key assumptions [10].

For linking BIM and LCSA at the building and neighborhood level, there exist various theoretical and practical integration approaches and numerous case studies with different scopes (level of detail (information and geometry), life cycle phases and number of parameters considered) [11]–[13]. Furthermore, it is apparent that BIM-LCSA integration is increasingly being shifted to the early planning phases [14]. However, both the integration of urban environment parameters and the consideration of sustainability during the preparation of development plans as part of municipal urban planning are currently only considered to a limited extent.

The linking of scenario modeling and sustainability assessment procedures within the scope of the possibilities of the development plan therefore appears to be appropriate and is described subsequently.

## 2 Development plan based LCSA using BIM

In the context of the challenge described, the three areas of development plan, BIM and LCSA should be merged. A multi-layer approach is used for this, which can be broken down into the three layers of data, application and user. As Figure 1 illustrates, data from various sources is collected, processed, analyzed and made available to the user for decision-making. For the concept developed for this purpose, first the substantive procedure and then the technical implementation are explained.

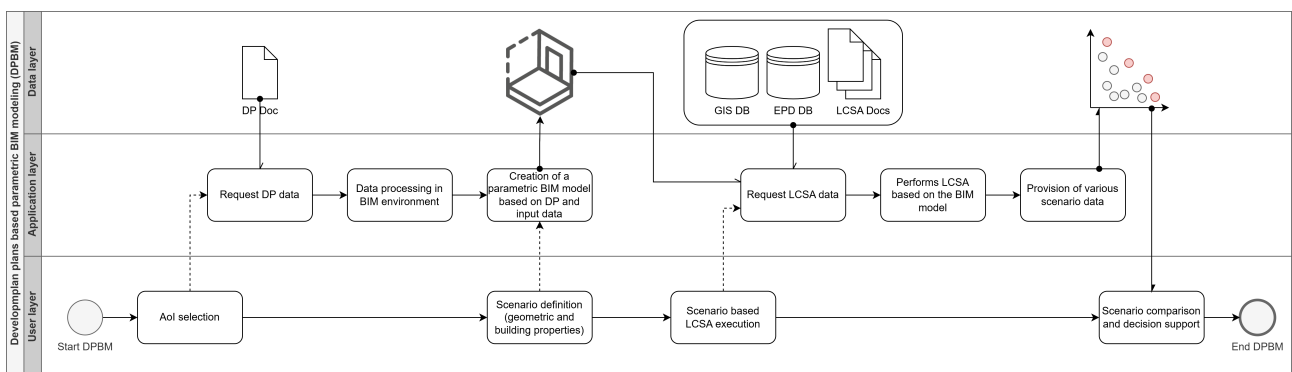


Figure 1: Concept overview, broken down by user, application and data layer (DPBM = Development Plan based BIM Modeling; DP = Development Plan; GIS DB = Geodata from GIS (e.g. OpenStreetMap); EPD DB = DataBase for Environmental Product Declarations (e.g. Oekobaudat); Doc(s) = Document(s))

## 2.1 Concept

For the application essentially two optimization points were identified: Development plan preparation (taking sustainability criteria into account) and sustainability-conscious neighborhood/building planning in compliance with development plan specifications. Both areas, the preparation of the development plan and the final implementation of the specifications and consideration of sustainability goals in accordance with regulations, are therefore very time-consuming and complex.

In order to take sustainability requirements into account and identify resource and environmental hotspots when creating development plans, various scenarios are formed for specific development plan areas (Area of Interest - AoI). Ecologic (environmental impacts), economic (costs) and social (comfort and environmental analysis) data are retrieved from LCA databases, literature values and geo-reference data, and linked with each other on a model and rule basis. The generic and average values used are suitable for the uncertainty that still exists at the time of application of the approach with regard to costs, environmental impact and building design aspects. Using this approach, a combined analysis of these criteria can be carried out for different types of neighborhood and the resulting values can be used as a decision-making support for parameter variation and definition in the development plan creation and neighborhood/building planning process. During the planning phase, sustainability reference values can initially be specified and then checked for compliance by running numerous possible general scenarios.

The data for the analysis comes from two main sources: user input by a decision-maker or planner of the development plan in the municipal service and deposited data from databases and literature values. The user input relates primarily to the geometry of the object and the selected construction type. The stored data for the overall life cycle assessment (e.g. GWP - global warming potential) comes from the German EPD database (Ökobaudat), whose generic data sets are supported by scientific studies. GWP is used as an LCA indicator in the case study as an example. All LCA levels (A1-C4 + recycling potential) are aggregated to calculate the total value for the entire service life of the building component. The cost data comes from the BKI cost catalogue (de: BKI Kostenkatalog) and the geo-referenced environmental data is retrieved via the Overpass API, which can be used to access OpenStreetMap data. With this data, a uniform scenario database for the further calculations is created. Pareto Optimum (cf. Figure 3) can then be formed from the data of the LCSAs in order to determine the most suitable configuration for the defined priority of sustainability. A modelling approach has therefore been developed that combines the various areas of development plan preparation, BIM and LCSA in a simple way to enable municipal decision-makers to demand and promote sustainability requirements through informative scenario creation and analysis.

## 2.2 Technical implementation

For the technical implementation, existing software architecture was used. Both the BIM authoring software Revit and the Dynamo extension, which is already natively integrated in Revit, were used for this purpose. Revit is only used for the geometric representation and evaluation basis of the 3D BIM models created. Dynamo is an open source extension for Revit that serves as a program interface between the created program code and the Revit model in order to implement automatic processes. By starting the developed Dynamo application, decision makers can select different parameters for the

modeling to simulate different scenarios. This is done via an user interface in which parameters such as the number, height and roof shape of the objects can be selected. As part of the modeling process, the development plan is first converted into a format that can be interpreted by CAD systems. Then, a sub-area of the entire development plan is selected (AoI, see Figure 2a) and the relevant development plan parameters are identified (building line, distance area, type and extent of building use, construction method, maximum and minimum dimensions, etc.). The area of interest is subdivided into smaller plots depending on the type of development selected. This serves as the basis for cubature modeling, which generates the floor levels, the exterior walls and the roof. The roof then adapts to the last floor and is generated on top of it. Finally, a geometry is created for the interior walls, which supports various apartment layouts. Depending on the floor area and the chosen parameters, it gets divided into one or more sub-areas, in which the parametrically pre-defined apartment plans of the individual apartments are integrated (cf. Figure 2b). The floor plans used are based on a range of standard apartment layouts and can be chosen by the user.

Four different construction types serve as the basis for the layout of the different parts (outer- and inner walls, roof, floor): Brick, Concrete, Wood and PreCast-Concrete. Each of these construction types not only defines the general cross-sectional geometry of the respective building parts but also categorizes the materials used for environmental impact calculations. The data addressed for this purpose comes from an EDP data bank (Oekobaudat) and is requested at runtime using an API and linked to the intended model elements. In this step, the material data available as XML is processed using Python code within the Dynamo framework. The total GWP for each material is calculated, linked with the dedicated material category for each part and then, the sum between every material from each category is formed, to get every possible combination of parts.

The social indicator is determined by the size of the living area per person, access to public transport and the distances to various social infrastructure facilities such as schools or hospitals. This geodata is requested and processed using an API to the geodata database Overpass by comparing the coordinates of the object area with the stored data from Overpass. The social indicator is then determined from this data, with a high index being classified as good. A breakdown and weighting of the various social criteria would also be possible.

The results from the BIM model are saved as a CSV file that contains all relevant information (e.g. number of floors, GWP, apartment size, etc.). Various model data can then be analyzed and compared using a Python script. For this purpose, a multidimensional (3D) Pareto front is created from the parameters cost, GWP and social of the various created objects and compared with each other. The Pareto front (cf. fig. 3) considers all factors simultaneously and evaluates them without neglecting any other factor. It is also possible to only analyze the models in regards to one or two of the parameters, if needed. Both the different geometries and the types of construction used are taken into account.

### 3 Use Case

The approach developed is implemented as part of an application example. The relevant information (development plan parameters) is extracted for a development plan sub-area (AoI) and automated neighborhood modeling is carried out. The preliminary process of semantic acquisition of development plan information is explained in Schönfelder et al. [15].

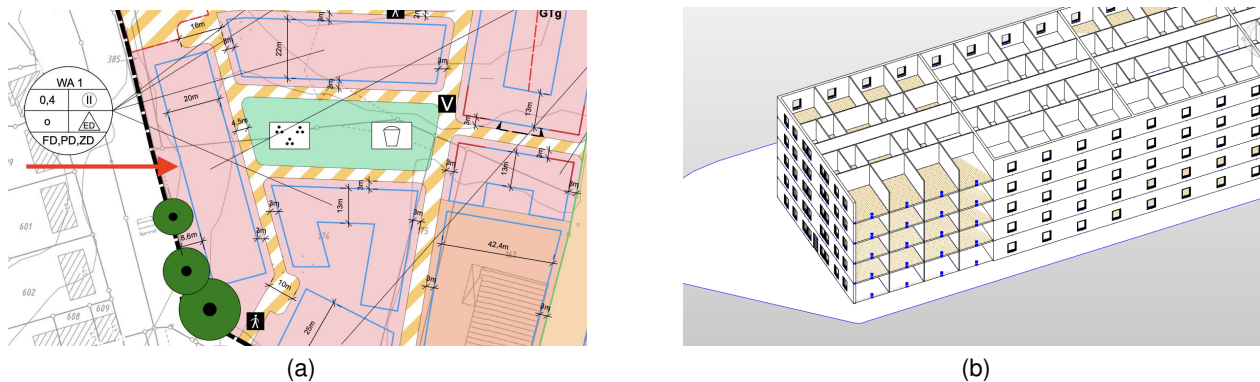


Figure 2: (a) Cutout of existing Development Plan (DP), (b) Cutout of DP-based BIM-Model

For the use-case, a sub-area from a development plan located in Witten, Germany is used as a template. Decision-making for the selectable parameters is simulated. For this purpose, several buildings with different geometries and construction methods are modeled for the property and then analyzed.

The size, number of residents and type of property are varied in order to capture and compare as many building types as possible. To be able to compare the results with each other, the respective data is normalized to the per person value. Detached apartment buildings, terraced houses and individual residential units were simulated as building types. Different roof shapes, apartment layouts and building materials were used. In addition, the retrieved and subsequently calculated LCSA data is visualised in a 3D Pareto front. This reflects the trade-offs between the three sustainability criteria assessed. The Pareto front provides information about the most efficient solutions where an improvement in one criteria is not possible without worsening the performance of another. Solutions that lie on the 3D Pareto front represent the best trade-offs and offer the most efficient options in terms of GWP, costs and social. For the three-dimensional visualisation, one criteria from each sustainability area was compared. A dedicated comparison is also possible. This information is helpful for decision making when selecting the optimal neighborhood or building design for certain circumstances and objectives.

The results of the case study based on an existing development plan show advantageous values for the used material wood and prefabricated concrete, due to their low CO<sub>2</sub> emissions. In addition, the construction of terraced houses and apartment buildings is favored, as they offer a higher level of living comfort (cf. Figure 3). In the Pareto front, the best results for the different categories can be seen: Precast concrete apartment building is the most economical, wooden apartment building the most ecological and the multi-family-house has the highest social-indicator. The wooden multi-family-house performs the best among all three aspects.

## 4 Conclusions

The main focus was on the creation of a modeling approach for the integration of urban planning requirements from development plans, environmental parameters (e.g. accessibility) and the multi-

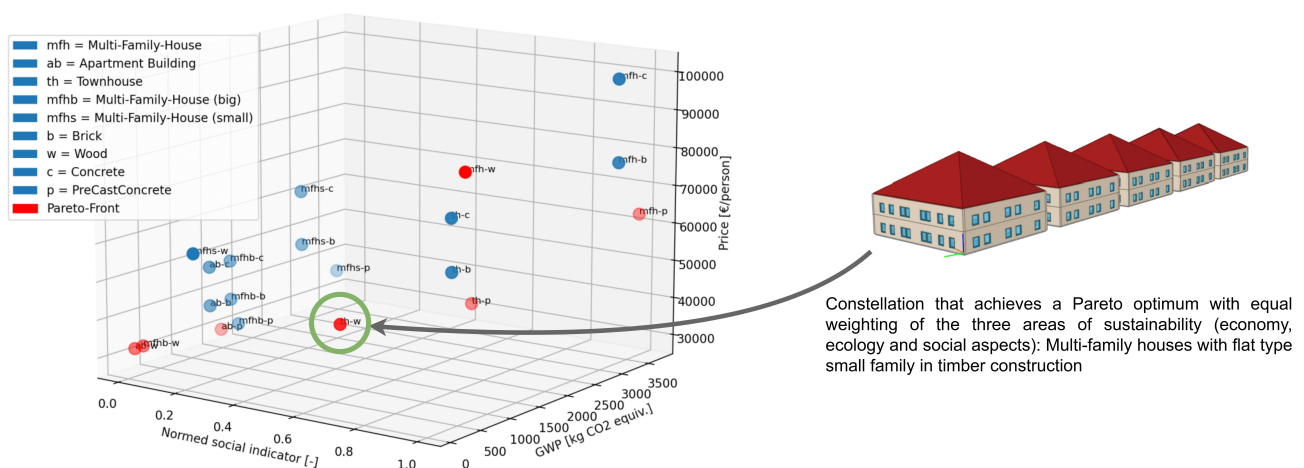


Figure 3: Left: Pareto Optimums for multi-criterial LCSA; Right: Pareto Optimum equal weighting of the three areas of sustainability

criteria sustainability assessment in combination with BIM. Depending on the sustainability priorities of a municipality, different scenarios can be created and compared. Ultimately the most suitable one can be selected for further neighborhood planning. By calculating the Pareto optimum, it is possible to determine and visualise these priorities. Using multi-stage modeling, relevant geometric and semantic parameters were retrieved, linked and used for sustainability assessments. For the scenarios considered in a case study, it was demonstrated that by determining the Pareto optimum for various sustainability criteria, a basis for decision-making was created that does not focus solely on the cost criteria, as is often the case in current practice. The authors conclude that this early consideration of sustainability on the basis of development plan parameters as part of neighborhood planning can improve the later sustainability performance of constructions

The approach currently focuses on greenfield sites and new buildings. Additional potential can be exploited by considering existing buildings and adding further sustainability approaches such as climate and soil analyses. To furthermore strengthen the results and make the analysis more precise, additional factors could be taken into account, such as access to natural light, noise pollution, usage of recycled material and cost values for different parts and life cycle stages. Especially for the social aspects, a broader research basis for linking specific living parameters with the perception of their residents would be advantageous.

In general, as also demanded by the Roadmap Circular Economy, more standardization for sustainability calculation methods and data collection, and a uniform mandatory database for environmental, product, component and material data would be desirable. The establishment of a standardised level of information need would be the objective for this.

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