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Development Of A Digital Planning Tool For Dimensioning And Investment Cost Calculation In An Early Factory Planning Phase

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Abstract

As an interdisciplinary task, factory planning represents a key factor for logistics, supply chain and ultimately, the economic success of companies in the manufacturing sector. In factory planning projects, the focus is on the early planning phase, where costs and the associated misinvestments can still be significantly influenced. The challenge lies in the early valid dimensioning of the planned factory despite fuzzy data to provide decision-making support regarding the investment costs. In this context, this article presents the development of a digital service and planning tool based on a scientific procedure model. For this purpose, the research needs are first derived, reference is made to a scientific procedure model and the requirements analysis for the tool is presented. The tool developed on this basis aims to dimension and economically assess planned factories at an early planning stage. In this way, decision-makers in companies will be provided with data-based results to make future-oriented decisions between different project scenarios.

Keywords

Digital planning tool; factory planning; dimensioning; investment cost calculation; feasibility study; early planning phase; uncertainty

1. Introduction and need for research

In the course of increasing customer requirements and the rising number of product variants, the need for planning production systems is constantly growing. Factory planning as a critical factor for the economic success of companies is thus becoming an interdisciplinary and permanent task [1]. The planning object can range from the re-planning of individual operating resources to entirely new plants. The effects of the planning decisions have a significant impact on the future cost structure and, thus, on the economic efficiency of the production systems [2,3]. To systematise the various planning activities and make the complexity of the planning process manageable, multiple approaches have been summarised in VDI Guideline 5200 [4]. The basic understanding of the classic factory planning process provides for sequential planning phases that lead successively from “rough to fine” to a detailed result. The approach of synergetic factory planning significantly contributed to the VDI 5200 procedure, which is widely recognised in practice. Synergetic factory planning combines production planning with a focus on the design of technological and logistical processes from a process perspective and object planning with a focus on interior and exterior design from a spatial perspective [3].

Overall, factory planning projects, especially new and expansion planning, represent a significant challenge due to the long life cycle and high investments [2,5]. Statistical evaluations show that cost targets of factory planning projects are missed in more than 70% of cases [6]. In particular, the early planning phase plays an important role in this context. In the early stage of factory planning projects, on the one hand, the project´s

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scope and, thus also, the associated costs are determined [2,5]. On the other hand, the early planning phase is fraught with uncertainty, and reliable information and data are often not yet available [7]. Figure 1 underlines this conflict. Although it is difficult to estimate costs in the early planning phase due to the lack of information, it is essential to avoid misinvestments. Only in this early planning phase can costs be influenced with sufficient flexibility. Often a project cannot even be started without a budget estimate. Conversely, costs cannot be estimated if the project has not yet started. For this complex problem, a solution needs to be found.

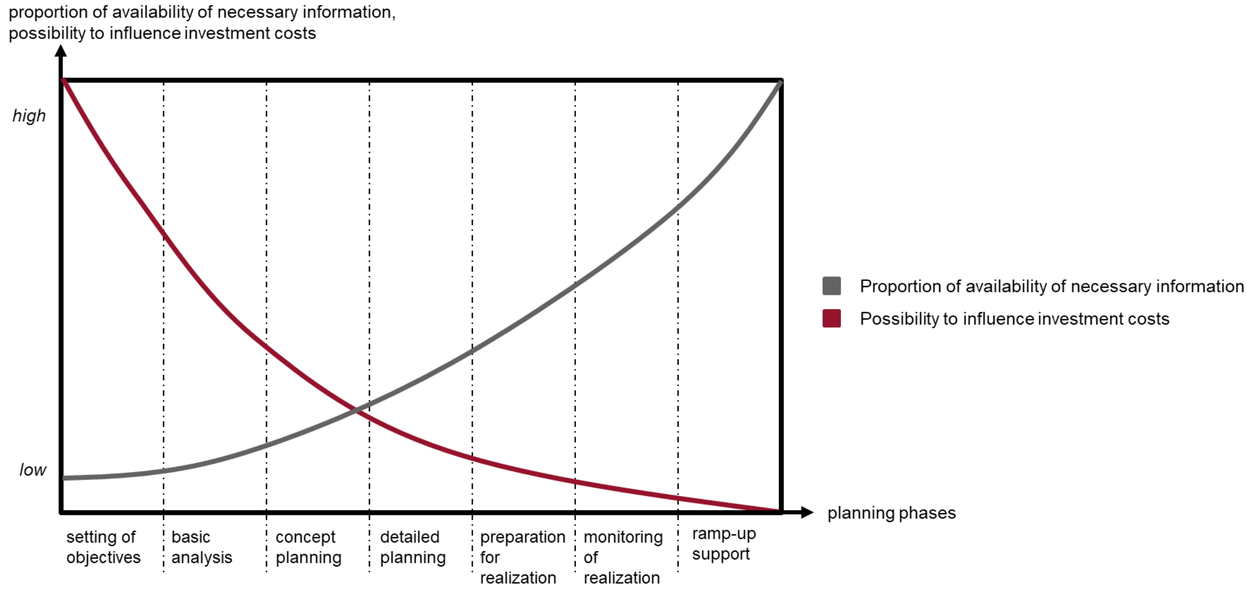

Figure 1: Cost incurrence vs cost influence - own figure based on CHOU and ZEHBOLD [8,9]

Previous work [10–12] has shown that for example feasibility studies in an early planning phase and digital planning tools for dimensioning and investment cost calculation can help address this problem. Furthermore, as previous literature research has shown, some approaches already exist in this area. Still, they do not sufficiently represent the early phase, uncertainties and the calculation of dimensioning variables (personnel, operating resources and area) for estimating investment costs [12]. Therefore, this paper presents a digital planning tool that can serve as decision support for the investment cost estimation of planned factories in an early planning stage.

2. Procedure model

In previous work, a model has already been developed that outlines the scientific and practical procedure for estimating costs in an early planning phase before detailed planning starts (see Figure 2). For this purpose, planning information and planning tasks are first derived in a three-stage model. This is done in the course of a module model, which defines input and output parameters in individual planning modules. In the second step, calculation options are derived for the three main dimensioning variables: operating resources, personnel and area. Since sufficient information is not always available in the early planning phase, relevant surcharge, cost and uncertainty factors are identified in the third step. The procedure should consider both the process perspective from production planning and the spatial perspective from architectural planning and thus underline the importance of synergetic factory planning [12].

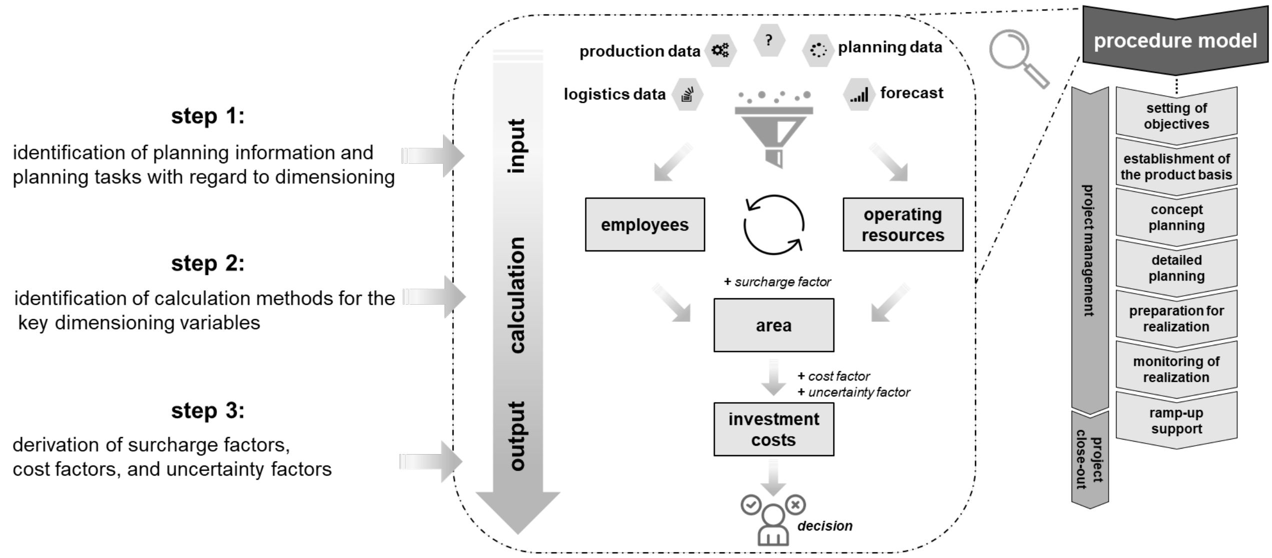

Figure 2: Procedure Model [12]

This procedure model creates the structural framework for standardised dimensioning of the factory to be planned with a small amount of information in an early planning phase and to be able to make monetary estimates on this basis. In order to develop a digital planning tool based on this procedure model various framework requirements were identified. These include the analysis of the early phase of factory planning, the consideration of uncertainties, the calculation of dimensioning variables and the derivation of the final investment costs [12].

3. Requirement analysis for digital planning tool

Digital planning tools in the context of the digital factory can achieve significant quantifiable advantages in planning factories. The main effects are the avoidance of planning errors, the reduction of planning time and the increase in planning quality [13,14]. Building Information Modeling (BIM for short) has also established itself as a cooperative approach to digital building modelling in the interdisciplinary planning environment, especially in the construction sector [15], but also successively in factory planning [16,17]. A few approaches and software solutions for building planning already exist [18,19] but are lacking in considering the process perspective. Final decisions in the context of dimensioning and calculation must still often be estimated by expert opinions [20]. However, this project aims to enable a software-supported decision-making basis for project managers with minimal effort. The overall requirements are, therefore, already derived from the project objective:

1. **Functionality:** The digital planning tool should be able to estimate investment costs despite uncertain data in the early phase.
2. **Usability:** Users should be able to use the tool with as little prior knowledge as possible.
3. **General applicability:** The tool should be applicable across all sectors without significant limitations.

To practically detail these overall requirements, a requirements analysis of the digital planning tool was first carried out according to a standardised procedure [21] to ensure that the system fulfils the intended functionality (see Figure 3). Inadequate requirements significantly influence software development and cannot be compensated for in later planning phases [22]. In general, a distinction is made between two types of requirements, functional and non-functional. Functional requirements define the functions, data and behaviour of the system [21], whereas non-functional requirements refer to the quality requirements such as reliability or availability of the system [23].

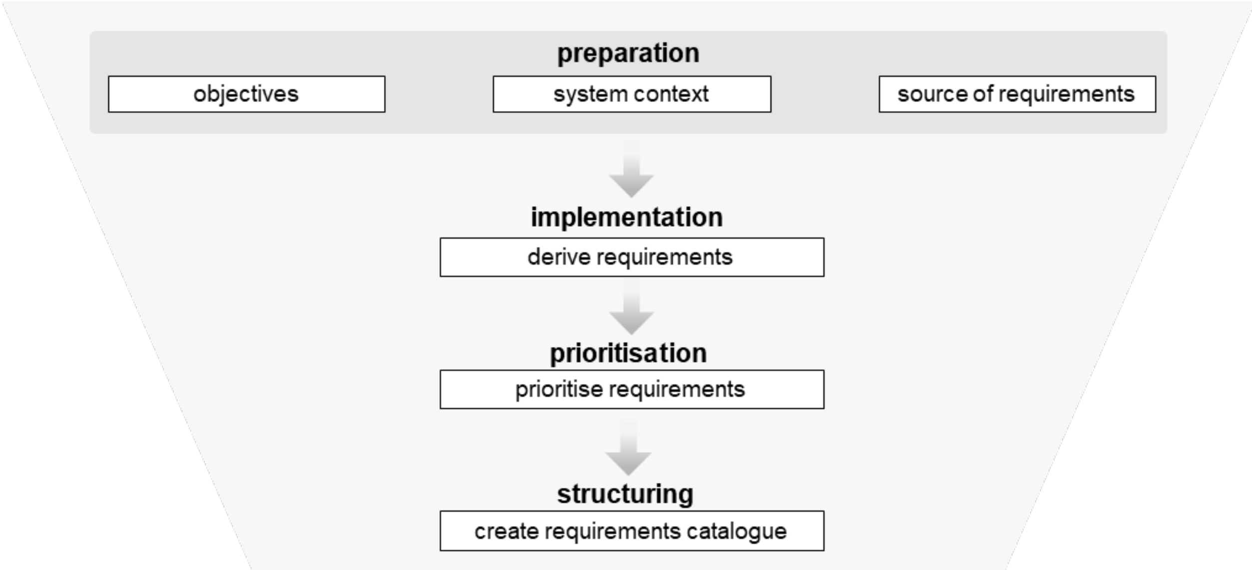

Figure 3: Requirements analysis according to RUPP [21]

By the procedure of a requirements analysis [21], the system context was first defined, the central goals identified, and sources of requirements determined. With this procedure, requirements could be derived and prioritised. Figure 4 shows an exemplary excerpt from the final requirements catalogue with clustered and prioritised requirements in personnel, organisation and operating resources.

requirement type	prioritisation	field	requirements
functional	significant	employees	A.1.8: number of employees A.1.9: working time A.1.10: working days, holidays
		organisation	A.1.12: order strategy A.1.13: manufacturing principles A.1.14: organizational forms of assemblies
		operating resources	A.1.15: machine variants A.1.16: machine area A.1.17: number of machines A.1.18: number of warehouse resources A.1.19: warehouse area A.1.20: warehouse levels

Figure 4: Excerpt from requirements catalogue

A simple data import, a fast calculation and an intuitive user interface were derived as central non-functional requirements. Furthermore, low-effort maintainability and optimisation should be ensured.

4. Development and use of the digital planning tool

The derived requirements (see chapter 3) now provide the basis for the software development and thus the selection of the development framework. The detailed procedure for developing the planning tool has been presented in previous work [10] and is not further discussed in this paper.

The programming language VBA (Visual Basic for Applications) was used for development. A key advantage of this programming language is its widespread use, which facilitates the further advancement and maintenance of the software. With the Windows Presentation Foundation (WPF), a user interface framework and part of the .Net platform from Microsoft was used. WPF uses the XAML markup, which defines application windows displayed to the user across the screen. The main advantage of an easy-to-use desktop application is the local execution of the programme, which is not dependent on web access. The speed of requests and calculation operations is also not limited by the internet connection. Data is stored and processed locally, so there are usually no additional requirements for data encryption [24]. The relational database system SQLite is used as the database, which was specially designed for use in embedded systems and fulfilled the software requirements [25]. The database can be stored as a local file and thus easily backed up or shared [26]. A standardised template in Excel format was developed to import ERP data (Enterprise Resource Planning data) into the database and application. For this purpose, the user has to provide and import the data in a predefined order. For the entire development, the integrated development environment Visual Studio was used, in which coding, debugging, compiling and the final deployment of the application is fully integrated.

In the following, the iteratively developed planning tool is presented, and its functionality is explained. The tool is used in seven simplified steps, as shown in Figure 5. As a **first step**, the data has to be imported. Templates are available to facilitate and standardise data import into the tool. The user downloads these and fills them with his machine data, bill of material, feedback data, etc. The data is then imported into the tool. After checking the correct entry of the data, the filled template can be imported and overwrites the previous data.

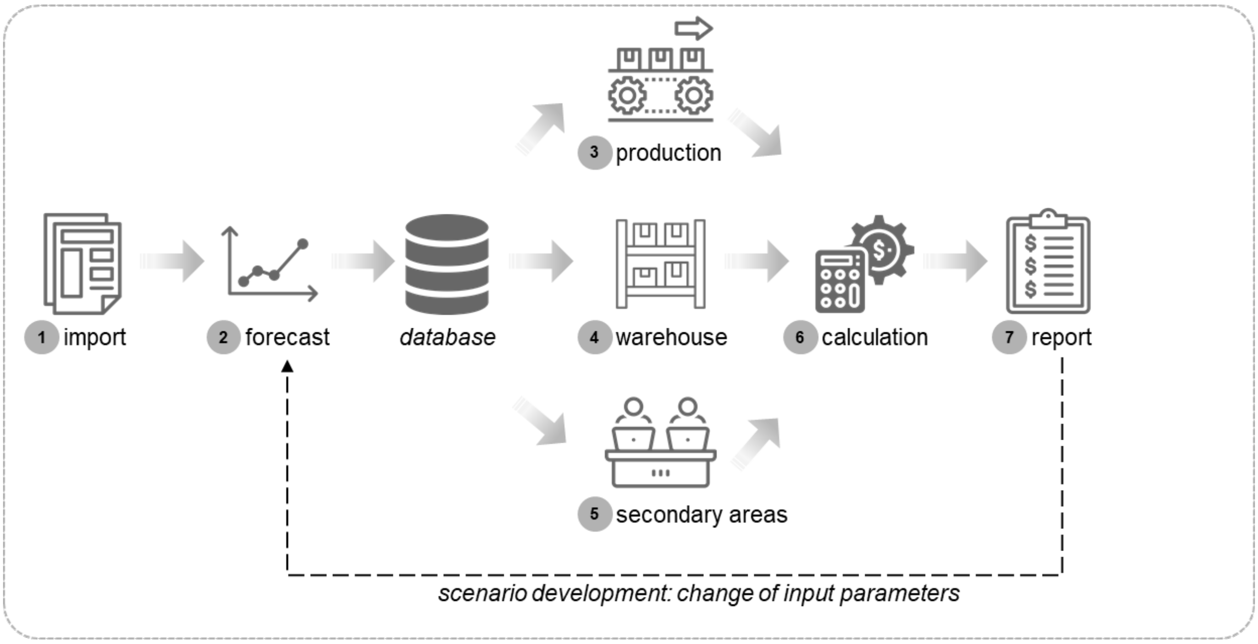

Figure 5: Tool use in seven steps

In a **second step**, forecasts of unit and production growth can be made. The user can decide which year is to be used as the basis for the calculation and define the start and end dates of the forecast period. Furthermore, an indication of the expected growth rates is necessary. In the **third step**, the production areas are dimensioned. In addition to the machine data already available, the user enters working time data. By comparing the capacity provided by the machines with the capacity demanded by the working hours, the software tool can derive the demand for machines and personnel and calculate the corresponding areas. The user can decide whether the substitute area method or the functional area calculation [2] should be used. The individual surcharge factors, e.g. maintenance and operation, are automatically added to the basic machine areas of the workplace directive [27]. Path areas are also considered with the help of a surcharge factor, which was determined as a practical value from numerous past projects. Depending on the favoured means of transportation, 25-30% is added to the production area [3]. At any time, the user has the option to overwrite calculated values with their empirical values and safety margins. In the **fourth step**, the required warehouse areas are dimensioned. The starting point for this is, among other things, the storage carriers, their dimensions and their number. Furthermore, an indication of the temporal range of the warehouse stocks is necessary. The user can make entries in the form of operating hours and days or as a proportion of the annual production. The digital planning tool calculates a warehouse area requirement based on a 6m x 6m warehouse module, to which additional area and safety factors can be applied. In the **fifth step**, the so-called secondary areas are dimensioned. It must be considered that in addition to production and warehouse, areas must also be provided for indirect functions. These are subdivided into the categories of functional areas (e.g. quality assurance, laboratories or shop floor management areas), social and office areas (e.g. break rooms, canteens or customer centres), and sanitary areas (e.g. changing and sanitary rooms or first aid).The main scaling parameter for this is the number of employees per shift. For standard values defined in the workplace guideline, the secondary area is calculated automatically using the determined number of employees ([28]), which can, however, be overwritten by the user with own specifications. In all three categories, additional project-specific areas can also be added. In the **sixth step**, the space requirements for production, warehousing and secondary areas determined in the previous steps are summarised and monetarily assessed. This assessment can be made either based on the areas (€/m²) or the room volumes (€/m³), for which additional height information must be provided. The cost factors that lead from the dimensioned area to the costs are based on comparative projects in the construction fee schedule [29], but the user can also adjust. The possibility of adjustment has proven useful insofar as, depending on the process area (production, warehouse, etc.), different requirements are demanded by the area or space (load-bearing capacity, clean room, etc.). A two-storied hall, for example, also requires higher cost factors per m² due to the necessary massive supporting structure. By adding up the individual items, the costs of the entire planned factory can thus be determined. At this point, safety factors and surcharges for the technical building equipment and construction areas can again be included. In the **seventh step**, the results are summarised and available for download in an Excel report. In this way, all entered parameters and results are documented. This also enables the area and costs of different scenarios to be compared based on other input parameters, such as forecast change.

Figure 6 shows an exemplary section of the tool from the sixth step, in which the individual area requirements are summarised and monetarily evaluated according to different requirements in their functions. According to step 7, a report can be generated now that presents the total area and costs.

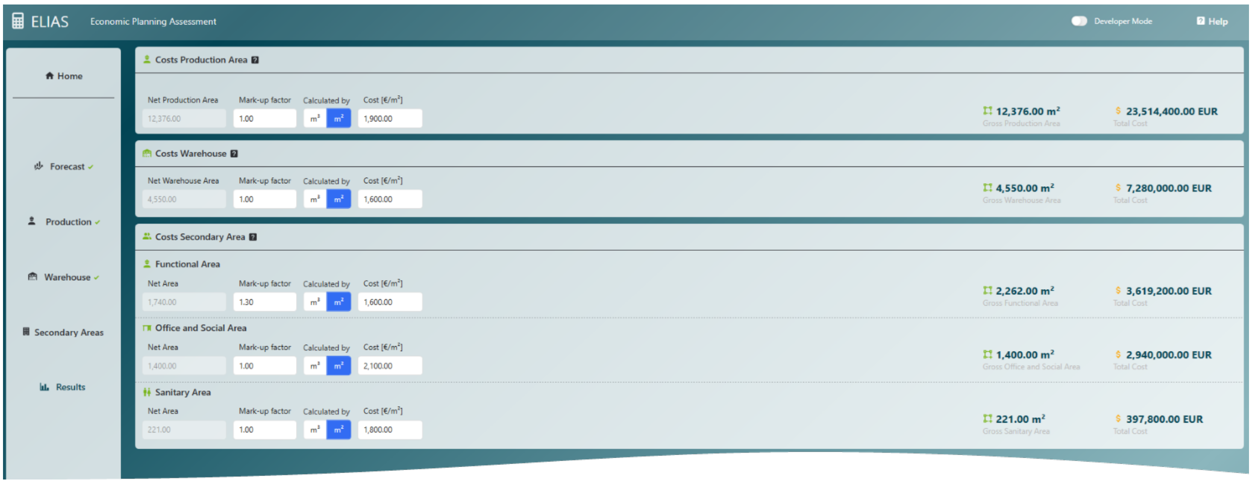

Figure 6: Excerpt from planning tool in step 6

5. Limitations and need for further development

With the result of the planning tool, the user is provided with the investment costs of the planned factory construction based on the process-side input factors with comparatively little effort. In addition to the numerous advantages of the planning tool for decision support in the early planning phase, some limitations must be addressed. Despite the software support, early cost estimation can still be time-consuming in some cases. Data and information must be collected and prepared before they can be processed as templates in the software tool. This data collection effort can be even greater, especially in new planning projects, when specific information and processes are not yet known. In this case, reference processes must be developed first, which can be fraught with uncertainty. The static template affects the flexibility of the implementation. To adapt the template, it is first necessary to analyse different data sets and validate and adjust the tool accordingly. Furthermore, the complex warehouse calculation needs to be revised, and different warehouse types must be integrated as a selection option. In addition, there is a need for further development in the integration of various target fields of factory planning (changeability, sustainability, etc.). The prioritisation of specific target fields could also have area-related or economic effects. For example, growth areas would directly impact area and area-related costs. A process-related enlargement of the column grid would have cost-related influences in the form of a more massive supporting structure. Another general limitation of the tool is the one-sided consideration of investment costs. Particularly with regard to energy consumption and costs, a parallel scenario-based assessment of the associated operating costs can be identified as a central need for further development. Integrating the operating costs could enable holistic decision support in the context of a total cost of ownership assessment. A system administration concept was developed to ensure the tool’s ongoing usability regarding technology and content and to identify the need for further development.

6. Conclusion and outlook

New planning and expansion planning, in particular, represent capital-intensive factory planning cases and thus significantly influence companies' profitability. In a turbulent market environment, there is a lack of suitable approaches that can reliably estimate planned projects in monetary terms despite high uncertainty. Costs can only be influenced sufficiently in the early planning phase. The planning tool developed in a cooperative approach between science and industry and presented in this paper is intended to provide a solution to this problem. The tool enables the user to estimate investment costs for planned factories based on process-side input factors with comparatively little effort and thus provides a decision-making aid for project planning. The prototype developed meets the requirements derived, but still needs further development that has identified. In addition to the general validation of the tool, the focus is on the integration of operating costs. The operating costs, along with the investment costs over the entire life cycle, determine the economic efficiency of a factory, particularly from a sustainability perspective. Only a combined consideration of investment and operating costs in the context of a total cost of ownership analysis can also provide holistic decision support. Investments and operating costs have to be considered from both a space and a process perspective. This identified need for research should be addressed in future research projects.

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