A metamodeling approach for the simulation of energy and media demand for the brewing industry

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Abstract
Due to economic, social and technical trends, as well as rising energy costs, the food and beverage industry is challenged to work energy-efficiently. Small and medium-sized enterprises in particular lack of both time and knowledge to identify and implement suitable energy efficiency measures. With the help of simulation, decision-makers can pursue numerous approaches and make well-founded decisions. A metamodel based on four modeling pillars (physical-, process-, article/recipe-, and production plan model) for an entire production system concerning the forecast of energy and media consumption is presented. The metamodel is implemented in a user-friendly modeling tool, which enables a simple hybrid modeling without prequalification of the user. Subsequently, a standardized data exchange file, as basis for a simulation model, is generated. For validation, various use cases were modeled and the tool was validated using a systematic test. In addition, two simulation studies were performed to show that the presented approach provides the opportunity to create a holistic model in terms of forecasting energy and media consumption.

KEYWORDS
brewing industry, energy demand, metamodel, modeling, simulation

1 | INTRODUCTION AND OBJECTIVE

The energy-intensive production of food and beverages is a challenge to the manufacturing industry due to political, economic, environmental, and social conditions.[1,2] The high market dynamics, which require a large product range and extremely flexible production, are special for the beverage industry. Through energy-efficient production, costs can be sustainably reduced and competitiveness can be increased.[3,4] In the last few years, there have been enhanced attempts to further develop beverage production in terms of technological performance or to improve its energy efficiency. This is often achieved using catalogues of IT-based measures and software tools.[5–7] In an earlier work of the authors, various methods for improving and uncovering optimization potential concerning energy and media efficiency in the beverage industry were examined. It was shown that the application of simulation, compared to other methods, proves to be most suitable for a holistic analysis to uncover optimization potentials and to test different scenarios. Its advantage is that complex, cost- and time-intensive real experiments, which result in a stop of production, can be avoided. Especially in connection with a production plan, simulation studies allow the greatest possible flexibility.
Previous approaches are either limited by their focus on only one type of energy and mostly serve only partial areas of production or the underlying model as the basis for validation is not sufficiently realistic or only incomplete.\(^8\) There are numerous challenges in the implementation or application of the software solutions, which mostly lie in the generation of models. These are related to the creation itself, but also to limitations caused by the companies, especially small and medium-sized enterprises (SMEs), themselves. This is reflected in the lack of financial and human resources.\(^9\) Therefore, the precise specialist know-how in the field of modeling and simulation is often missing.\(^10\) Also, the amount of required data and parameters is very important, especially when mapping an entire production plant. An upstream problem is usually the missing information along the process chain and the plants and machines.\(^11\) The beverage industry is characterized by a high complexity due to the number of devices and machines, different production processes, which are dependent on biological and chemical influences, and the high speed of packaging processes. Due to numerous heating and cooling processes, the brewing process is one of the most energy consuming manufacturing process in this industry sector.\(^1,12\) Precise knowledge of its processes is essential to meet the required product quality and optimize the process efficiency.\(^13\) Furthermore, the German brewing industry, for example, is characterized by SMEs (yearly production <50,000 hl), as they represent approx. 90% of the companies.\(^14\)

Based on the results of the authors previous literature work,\(^8\) a modeling approach for uncovering the potential for increasing energy and media efficiency by simulation is proposed. The prerequisite for this is a formal description and definition of a uniform data structure for the system. A metamodel is a suitable approach.\(^13\) It should set the framework to represent production plants holistically in a generic and hybrid way. Consequently, it could be used for all different companies in the beverage industry. Concerning the recording of the parameters required for simulation, such as information about material flow or energy and media consumption, no standardized procedure has been available to date. Furthermore, by describing the required data basis and structure, a metamodel can provide first principles for this. Moreover, a combination of batch-oriented and discrete operation in the beverage industry is not described in a model yet.

This paper presents a holistic, generic and hybrid modeling approach for production systems in the brewing industry with regard to the energy and media consumption. Consequently, a metamodel, covering all production areas, as well as production processes, articles, recipes and the production plan, is presented. This should serve as a basis for the creation of models, which map the structure and all required parameters needed for a later simulation. To achieve this, a software solution, which incorporates the metamodel elements, is presented. The aim of the modeling environment on the one hand is a simple and fast creation of models without specific prior knowledge and expert know-how and on the other hand the possibility of favorable forecasts for energy and media consumption. This can be achieved by the generic model, which should represent any variants of production systems. As a result of the modeling environment, an exchange format containing all relevant simulation parameters is created. This provides the basis for an easy creation of simulation models, independent of the simulation environment. Subsequently, simulation experiments can be performed. The application of the metamodel is shown with examples from production companies. The modeling environment is validated with respect to the requirements, especially with regard to the barriers of SMEs. In order to demonstrate the suitability of the overall methodology exemplary simulation studies for the batch and the discrete area were carried out.

## 2 | THEORETICAL PRINCIPLES

### 2.1 | Beer production and packaging process—challenges for modeling a production system

According to the German Purity Law, only the four raw materials, malt, water, hops, and yeast are allowed be used to produce beer. In the following, the beer production and bottling process are briefly outlined, with details about the main systems and processes involved. The production process in the brewhouse begins with the milling of the malt in the malt mill. The next process step is the mixing of the grist with warm brewing water in the mash tun (mashing). The mash is heated in different temperature ranges for a certain time and then lautered in the lauter tun. During this solid–liquid separation, the husks are separated from the wort. The wort produced is heated and cooked in the wort kettle for about 1 h.\(^13\) Afterward, the wort is cast out and cooled down by the wort cooler. The gained heat can be reused in the process, for example, for mashing. Depending on the configuration of the brewhouse, the number of brews per day may vary. The bottleneck of a brew house is the lauter tun. When the brewhouse work is completed, the cold wort is pumped into a fermentation tank and yeast is added. The yeast starts the alcoholic fermentation and decomposes the fermentable sugars into ethanol and CO\(_2\). The CO\(_2\) obtained is processed and can be reused at numerous points in the brewery. During the fermentation process the tank is cooled continuously. After fermentation, the young beer
is stored in storage tanks to stabilize and eliminate off-flavors. Most beer types are filtered or centrifuged. The finished beer is then pumped into bright beer tanks and is ready for bottling.\[16\]

The challenges in modeling the batch area of the brewery lie in the numerous different plant combinations or sizes as well as the different production process possibilities. These vary depending on the requirements for the beer style being produced and on their quality requirements. Some examples are described below: In the brewhouse, for example, a lauter tun or a mash filter based on the principle of pressure filtration, may be used.\[17\] Besides an infusion mashing process, a decoc-tion mashing process using a mash pan may be utilized. In the second alternative, one part of the mash is boiled up in the mash pan and then returned to the original mash. There are numerous possibilities when choosing the boiling system. Besides the use of a wort kettle, as described above, systems such as thin-film evaporation or a gentle boiling system can be used. The approaches for fermentation and storage of beer vary from single-tank processes in cylindroconical tanks to the use of three tanks for fermentation, maturation, and storage. In the production of beer, many different approaches and possibilities are pursued in terms of plant configuration and process control.\[18\] These approaches vary greatly depending on the size of the company as well as the variety of products. For example, a microbrewery producing up to 1,000 hl per year has a different number and size of devices than a large brewery producing several million hl per year. The quality of the products also has a decisive influence on the production processes and the choice of equipment.\[19\] The challenge of modeling the batch area of the brewery lie in the representation of all possible plants and their combinations. Besides this, it must also be possible to adequately model all processes in terms of their energy and media requirements.

The plant structure of the packaging area varies depending on the type of packaging (e.g., kegs, bottles, and cans), the packaging material (glass, PET, and aluminium), and the packaging concept (disposable and reusable).\[6\] Manger et al.\[20\] describes the variety of machines in beverage bottling plants. Due to the high complexity, the plant structure of a bottling plant for returnable glass bottles is described below. Buffer conveyors connect the individual machines. In combination with increased output of the central unit, usually the container filling machine, those conveyors serve to buffer any pre- and succeeding failures in order to ensure trouble-free production. The emptied crates brought into the beverage bottling plant must be unstacked from a pallet by the depalletiser. The emptied crates are transported by a crate conveyor to the decrating machine, which has the task of unpacking bottles from the crates

and placing them on a container conveyor belt. This conveyor belt transports the bottles to the bottle-cleaning machine, where they are cleaned and disinfected after which they are ready for refilling. The empty crates are also cleaned and transported directly to the crating machine. The cleaned bottles are inspected for various features by the empty bottle inspector after which they can be filled with the appropriate product and sealed in the container filling and sealing machine. Afterward, the bottles are provided with labels by the bottle labeling machine and are repacked into the cleaned crates in the crating machine. These are then stacked on pallets by the palletiser and transported from the plant to the warehouse or logistics. A summary of the main consumers in the individual production areas according to energy and media type is presented by Bär and Voigt.\[8\] A detailed investigation regarding consumption in the packaging sector is described by Osterroth et al.\[6\] in a representative survey. Their work provides a good overview of the individual main consumers as well as the consumption structures. The challenge in modeling the packaging area lies in the mapping of different machine types and their different parameterization. These vary above all depending on the container type to be processed and its corresponding further packaging. The different process equipment for preparing the product to be filled and the transport equipment used within the system must also be considered.

## 2.2 Dependency of the energy and media consumption of the different production areas

The two production areas differ not only in their different production methods, but also in their dependence on energy and media consumption. In the batch area, the demand for thermal and electrical energy, as well as media such as water, compressed air, and CO₂, depend on the respective process. Consequently, approaches for modeling the batch area of a brewery refer to process modeling.\[21–24\] As Muster-Slawitsch et al.\[25\] have shown, the energy is required at certain times in the process. Due to simultaneously running processes and the superposition of consumptions, enormous load peaks can occur.

In the packaging area the energy and media consumption depends on the current operating state of a machine. Based on works on discrete working machines by Cataldo et al.\[26\] Osterroth et al.\[27\] proved that different energy and media consumption levels of packaging machines in the beverage industry relate to the current operating status. They defined corresponding consumption levels, which furthermore show a granular
distribution of consumption levels concerning time dependency within a given state. The available operating states and a state model are described by the Weihenstephan Standards, a definition of a data interface for packaging machines.\[^{[28]}\]

### 2.3 Application of standards for the classification of production plants

The production of beer takes place in a batch-oriented discontinuous way, as described in ANSI/ISA S88.\[^{[29]}\] This means that the same batches of beer are produced on specific plants using processes defined by recipes. Discrete manufacturing is used in the filling and packaging area of a production process. Here a piece-by-piece production takes place through the same work steps of the individual machines. The ANSI/ISA S88 describes standards for structuring a production plant by mapping the individual models to hierarchical levels. Figure 1 shows the subdivisions in levels of the physical model on the left side and process model on the right side. The dotted arrows also show the mapping to an example from the brewing process.

The physical model describes the physically existing plants and machines of a production plant. The relevant top-level comprises **process cells**, which consist of several subsystems required for the production of a batch. The second level describes **units**. An example for a unit in a brewery is a vessel such as the mash tun. **Equipment modules** are subordinate. These carry out several small process steps within a unit. The lowest level is described by **control modules**.

The process model is also divided into four levels. The highest hierarchical division is the **process**, which comprises a sequence of steps to produce a single batch. It is subdivided into **process stages**. In these steps, so-called **process operations**, which lead to a chemical or physical transformation are summarized. The lowest level is described by **process actions**. Furthermore, a mapping of the process model to the physical model can be derived from the S88 standard (dashed arrows). A process may only run on one process cell. In addition to a process stage, a unit can also be linked to process operations and process actions. Process actions, on the other hand, can also be executed on an equipment module.

Despite the different production methods in the packaging area, the S88 standard can also be applied here. Since the machines always work in the same way, no process model can be defined, but the division of the physical model can be transferred. In this case, a process cell corresponds to an entire packaging line. This means

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**Figure 1** Hierarchical subdivision of the physical (left side) and process model (right side) according to ANSI/ISA S88; dashed arrows show the possible mappings of the two levels; dotted arrows show an example of the respective level
that individual machines, such as the container filling machine, can be classified as units. Equipment modules represent individual motors or pumps. Control modules represent sensors.

2.4 Modeling of production systems for the simulation of the energy and media demand

The VDI 3633 norm defines a guideline for the procedure for simulation studies. The “preparation” development phase therefore also includes data determination and coordination as well as the creation of the simulation model. A model is an abstract representation of a complex problem or system, in which clear system boundaries are defined. The degree of detail is a measure of the accuracy with which a system is depicted in a model. A model thus has the function of depicting or designing complex systems more easily and is the result of a construction process in which the perception of the contents of a selected object is presented in a purpose-oriented way. Important for the simplification of a real system is the previous definition of the purpose of the model. Dangelmaier therefore describes system optimization with regard to system structure, behavior and function.

Metamodels can be used to gain a better understanding and generalization of the system. A metamodel represents only the essentials and serves to simplify the model. As a result, metamodeling is a practical but robust tool for interpreting and analyzing highly complex models. Simulation is usually only used for complex systems, which cannot be represented by mathematical-analytical methods. Since simulation can only be achieved by creating a model, the definition of a metamodel offers numerous advantages.

The scientific literature describes different approaches and methods concerning the modeling for simulation of energy and media consumption of beverage production systems. There are way more simulation and optimization approaches in the food and beverage industry regarding product quality and process optimization, but this will not be the subject of this publication. Supply chain models also provide a differentiated view of production systems, since business, delivery and decision-making processes are usually relevant. In the following, relevant publications in terms of energy and media consumption are briefly presented and the necessity and requirements for a metamodel are derived.

For the brewery, numerous approaches using a pinch analysis, an analysis of the thermal energy flows and determination of the energy available for use, are described. Mostly heat-exchangers or the integration of cogeneration plants are the objects of investigation. Mignon & Hermia used the software BATCHES for modeling and simulation of a brewhouse. The modeling in this tool is based on plants, recipes and production plans according to ANSI/ISA S88. The influence of the production plan on the thermal energy demand of the units of the brewhouse could be investigated. In addition to the investigation of the optimal plant configuration, an energy simulation was used to reduce the peak thermal energy demand. This method made the reduction of a brewery’s primary demand for thermal energy possible. Based on the software Engineering Equation Solver (EES), Muster-Slawitsch et al. modeled plants, processes, energy flows and the production plan of a brewery. Their presented models represent the thermal energy demand during the brewhouse processes and the cooling load of a brewery. In both cases, significant consumption peaks could be detected, which were tried to be minimized by changing the process parameters. Dilay et al. use numerical simulation to optimize a tunnel pasteuriser in beverage filling. By simulating the water and heat network a statement about the energy consumption in connection with the plant geometry could be made. Another possibility for modeling and simulation is via petri nets. Petri nets are models for the description and analysis of processes and systems. They are characterized by their simple description, clarity, and uniqueness. With the help of Java, which can be implemented in reference nets (a further development of high-level petri nets), simulations can also be performed. Using a simulation through reference nets, Nagel was able to reduce the steam requirement of a brewery. The modeling was carried out using a graphical and modular software tool. Hubert et al. carried out modeling based on reference nets concerning the reduction of the water demand of a brewery. The processes taking place were modeled in reference nets and genetic algorithms were used to determine an optimal production plan. Using the same method, Pettigrew et al. simulated water consumption and the potential for energy production by treating wastewater in a brewery. Hubert et al. also modeled and simulated the water consumption and wastewater quality of beverage bottling plants using reference nets. The modeling included the individual aggregates of the beverage bottling plant and their operating behavior in a simplified form. The cooling demand of a medium-sized brewery was simulated over 10 months based on reference nets. The ongoing processes were modeled using a two-level hierarchy. Furthermore, Hubert et al. presented a holistic approach to modeling and simulating a brewery, based on the concept already mentioned. Among other things, the entire electrical requirements of the production plant were simulated.
Modeling and simulation of energy and media consumption is also applied in other industrial sectors using diverse tools. Li et al.[44] deal with the petri net representation of the ceramic production process, which is characterized, similar to the brewing process, by the application of batch-oriented and discrete operation. The production of bio-ethanol with regard to energy efficiency is modeled and simulated using the commercial software Aspen Plus. Therefore, the production processes are depicted and simulations regarding different use-cases are performed.[45] The simulation and optimization of electrical energy consumption of manufacturing processes can be performed using the software Arena, and should serve as a good example for an easy to use tool, especially for SMEs.[46] A discrete simulation based on Microsoft Excel and Visual Basic in a dairy factory with regard to the water consumption by modeling all water streams and relevant units is done by Marchini et al.[47] Tokos et al.[23] uses a mathematical integer linear programming (MILP) model to analyze energy saving opportunities in a brewhouse with regard to heat integration. The MILP model was solved using the software GAMS solver Cplex.

Further publications concerning modeling and simulation in the brewing industry deal with the bottling area. Forster[48] describes an approach to simulate a packaging plant in terms of its energy and media consumption. The modeling is based on a specifically developed block library in Plant Simulation, which intends to increase flexibility concerning the level of detail and to provide a large number of machines and transport systems typical for this industry. Osterroth et al.[27] used Matlab- Stateflow to model and simulate the electrical energy consumption of the machines depending on their operating behavior. In this work, a simulation model based on the hypothesis that the electrical energy consumption of machines depends on their operating state and which is within time-dependent was developed. By defining consumption levels, a very good concordance with the real data could be achieved.

A few papers deal with a similar approach for depicting a production system and therefore are useful for this work. Weissenberger et al.[49] presented an interesting approach for modeling production plants in the beverage industry, by which a manufacturing execution system (MES) may be automatically generated. This involves, among other things, the modeling of plants and processes. The modeling approaches are based on existing standardizations and thus provide a good basis for this work. Chen et al.[50] describe the application of the method in the brewery and also present a software solution for modeling.

It can be concluded that a wide variety of methods for modeling production systems concerning energy and media consumption or its optimization have been used for the domain of beverage production. All modeling and simulation approaches have in common that they do not cover the entire production system. In the case of the brewery, only sub-areas, that is, batch- or bottling area, were represented. Moreover, none of the approaches consider all energy and media consumptions of a plant. Only Forster[48] describes a holistic simulation in the packaging sector. In the batch area, the most frequent investigations are carried out in the brewhouse regarding the consumption of thermal energy. Especially the mapping of both production areas is a great challenge due to the different production methods and energy and media consumption dependencies. Approaches for structured and generic modeling can only be found in references[49,50] but with a different focus. Approaches to the information and parameters required for a model are described by references[21,27] in each case area-specific. Currently, no (meta-)model, which includes the required information and parameters, is available for the holistic depiction of a production system of a beverage company. Although numerous tools and special software are used for the modeling, as described above, these are only of limited suitability, since on the one hand both production areas cannot be represented and on the other hand the operation, that is, the model creation requires special know-how and previous knowledge of the operator. Especially for SMEs, this is a barrier.

Consequently, the authors propose a metamodel based approach for the simulation of production systems in the brewing industry with regard to energy and media consumption. The structured and generic metamodel creates a basis for all simulation-relevant information and parameters. To enable an easy model creation and to overcome the barriers of SMEs, a software implementation of the metamodel is presented.

3 MATERIALS AND METHODS

3.1 Metamodelling in UML

The metamodel for production plants concerning the simulation of energy and media consumption is depicted using class diagrams in the graphical unified modeling language (UML) and is done with the commercial software Visual Paradigm Version 14.2 from Visual Paradigm International. Usually, UML is used in model driven software engineering approaches for the modeling of software systems but is nevertheless suitable for the representation of data models. The advantages of UML lie in defined terms and relationships and the resulting clear model specification of model components. Class
diagrams, in particular, are convenient in the regarded case to represent the metamodel consisting of classes with attributes, interfaces, and relationships. Classes comprise objects that are structurally identical and therefore have the same attributes. This abstraction allows the modeling of a delimited system. A class is represented by a rectangle with the name of the class. All attributes of this class are added to the rectangle. There can be numerous interfaces between classes, which describe the relationships. A general association (single arrow) represents relationships between classes or objects of classes. A composition (arrow with black diamond) means a special aggregation, which describes that parts cannot exist without the whole and are therefore existentially dependent on it.

### 3.2 Transformation from UML to XSD

The graphical and formal notation of UML allows representing the complex structure in an XSD (XML Schema Definition). Since the Extensible Markup Language (XML) is recommended as an exchange format, for example, between the modeling environment and a simulation environment, the advantage is that XML files can be described and thus verified by XSD. This also reflects the advantage of XML, which is a format for structuring and exchanging data and can be described in an application-specific manner using XSD. Other advantages of XML are its usability for a platform-implementation-independent exchange of data and its good readability by man and machine. Numerous transformation patterns are available for the automatic transformation of UML to an XSD. Starting from the metamodel, the transformation to an XSD for the description of the final data structure and the data content of the transfer file was carried out. The XSD has been edited using the commercial software <oXygen/> XML Editor 20.0 of Syncro Soft SRL. The advantage of describing the XML file via a schema is the description of the relationships, constraints and the order of data. In addition, classes or elements can be defined and their attributes, that is, content, data types and the unit, can be specified.

### 3.3 Development of a modeling environment

Based on the metamodel presented in UML class diagrams and the XSD for the formal description of the XML exchange file, a software-technical implementation could be performed. The implementation was done by object-oriented programming in C++ in the development environment Qt Version 4.10.2 (an application framework and GUI toolkit) by The Qt Company.

### 3.4 Systematic test for validation of the modeling editor

According to Schultewolter, a systematic test was carried out to evaluate the software-technical solution with the mentioned requirements, especially in SME. The validation and assessment in different factors for a modeling editor was performed based on Chen et al. 20 test persons, which covered a representative range of participants, as they had different levels of knowledge and previous experience in the field of modeling, were acquired to independently create and parameterize a model in the editor according to a given task. The tasks included all four modeling pillars as well as the interfaces between the individual models and thus provided a cross-section. As a first step, the test group was asked to model a brewhouse and a beverage bottling plant consisting of several elements as physical models. This includes the creation of a new element as well as the parameterization of the units. In the process model, two processes consisting of several process stages should be created and the process operation should be parameterized. Both processes were then assigned to the units of the modeled brewhouse in the recipe model. Two different articles had to be created in the article model and numerous machines of the beverage bottling plants had to be parameterized with corresponding article-dependent parameters. Finally, a production schedule had to be created for each production area. Additionally, a shift plan and corresponding mashing rhythms, as well as change-over/cleaning times, had to be inserted in a matrix. Following the systematic test, a questionnaire was drawn up. The poll included questions on previous experience with modeling and subjective impressions as well as the comprehensibility of the modeling approach and its implementation in terms of user-friendliness. The suitability of the modeling approach and the editor should be determined on the basis of the following four factors, see Table 1. The evaluation of the individual criteria should allow conclusions to be drawn about the usability and further benefits of the modeling tool.

### 4 RESULTS

#### 4.1 Generic metamodel for production systems with regard to energy and media consumption

Figure 2 shows an overview of the individual sub-models of the metamodel, presented in separate columns. The illustration in individual independent columns allows the hybrid and context-free modeling. The model columns
correspond to the categorization according to ANSI/ISA S88.\textsuperscript{[29]} The modeling approach refers to the unit level in the physical model and the process operation level in the process model. A more detailed approach might present the simulation of the overall system in more detail but would require an enormous increase in data and parameters. As a result, it would be too complex for the presented holistic modeling of complete production plants. The linking of the models with each other allows the representation of different recipes and articles with varying energy and media consumption. This flexibility allows the most realistic representation possible, which is necessary for the exact simulation of an entire production system.

The first column describes the physical model. Within this metamodel, a distinction between the model for batch-oriented operation and discrete production can be made. Units are represented by different classes, which also differ in their energy consumption behavior. The process model describes the running processes in detail down to the process operation level. The recipe model comprises, on the one hand, the recipes, which assigns processes to the respective process cells and units of the physical model. On the other hand, all articles, which can be produced on the discrete working plants of the physical model, are included. The fourth pillar, the production plan model, describes the production sequence, that is, the sequence of different recipes and articles on

| Criteria          | Evaluation contents                                                                                                                                 |
|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Simplicity        | Simple and fast creation of the models                                                                                                               |
| Comprehensibility | Modeling approaches and models are comprehensible and understandable                                                                              |
|                   | Model creation without specific knowledge                                                                                                           |
| Completeness      | Modeling approach covers the requirements and scope of the individual modeling areas                                                               |
| Sustainability    | Extent to which the modeling approach can be used (e.g., in other industries due to modification and extension)                                    |

TABLE 1 Validation criteria for the modeling editor (following Chen et al.\textsuperscript{[50]})

FIGURE 2 Structure of the metamodel for production systems (physical model, process model, recipe model, and production plan model); batch area (dotted areas); discrete area (dashed areas)
process cells as well as global framework conditions. The entirety of the models depicts a holistic production operation concerning all plants, processes, recipes, and articles, as well as the production plan.

4.1.1 | Physical model

The physical model follows the hierarchy of ANSI/ISA S88,[29] see Figure 3. Thus, at the top level, the class Physical_model comprises any number of Process_cells. Like the subordinate class Unit, this class has certain additional information such as specific IDs and identifiers. Any number of classes of the unit can be assigned to a process cell. Due to the different production methods and functions, there is a further subdivision into five different unit classes. These include Batch, Discrete and Conveyor units, as well as BranchMerge and SourceSink units. Batch_unit includes units that follow the batch-oriented mode of operation and have a process-dependent energy and media consumption. In addition to subclasses with further parameters, there are also the classes Consumption_factor and Recuperation_factor, which contain conversion factors for the consumption of energy and media as attributes. These factors are also used in the description of the process and recipe model and are described there in more detail.

The four remaining unit sub-classes associate Simulation_parameter in a composition. One object of the simulation parameters is the Technical_data, which varies in scope depending on the unit class. It represents the function of a unit concerning the mode of operation and parameterization of the material flow of the simulation. The Output_value describes the production speed of a machine, while the Capacity describes the units within a machine that are processed simultaneously. The InOut_ratio enables the specification of a packaging ratio of a machine, for example, the number of bottles within a secondary packaging. The attributes for Sorting-, Stocking-, and Storage_behavior enable the specification of product rejections, for example, by inspection machines, information on the processing method, or the storage behavior of units. Besides, the failure behavior based on the mean time to repair (MTTR) and the mean time between failures (MTBF), as well as the resulting availability is described in the class Failure_behavior.[56] The class State_data contains the consumption data (Energetic_parameters) for energy (electricity and thermal energy) and media (water, compressed air, CO₂) for the operating states Operating, Lack/Tailback, Failure, and Off.[27] This means that a specific consumption level for each type of energy and media is present at a certain operating state of a machine. Article_dependency enables, in conjunction with the recipe model, an article-specific specification of the simulation parameters including the subordinate classes. The unit class BranchMerge_unit describes the separation or merging of material flows and the unit class SourceSink describes the creation and

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**FIGURE 3** UML-class diagram for physical metamodel
destruction of material at the beginning or end of material flow. Both unit classes are essential for the function of a simulation.

### 4.1.2 Process model

The process model, as shown in Figure 4, follows the hierarchy according to ANSI/ISA S88. A Process_Model can contain any number of Processes. Further attributes of this class are a name and an ID. The subordinate classes Process_stage and Process_operation are structured according to the same scheme. Since the Process_operation level has been defined as the energy-relevant level, further attributes are defined here. The sequence of the individual process operations is defined using connections. The Process_operation_type describes the function of the process operation, such as filling, processing, or emptying. The Simulation_information contains attributes such as time and the consumption values for all energy and media types for a process operation. The Consumptions describe the total requirements of the respective energy and media type throughout the Process_operation. Considering the Recuperation_factor for energy being reused and the Consumption_factor of a unit in the physical model, the consumption values can be calculated. This allows a process- and unit-specific description of consumption, whereas a process can be performed on different process cells of a production system. The sequence of arbitrary process operations with a specific consumption of energy and media allows detailed mapping of a consumption profile to a process.

### 4.1.3 Recipe/article model

The Recipe_model (see Figure 5) covers all recipes, represented by a process and articles which can be run on process cells. The class of the Recipe_information has a name and an id as attributes. A Process_stage comprises the sequence of Process_operations. To be able to map the necessary flexibility of production in a brewery, process stages are assigned to units in the recipe model via the class Process_stage_link. This link results in the calculation of the consumption levels via the factors explained in Section 4.1.2. This offers the advantage, that the process model is independent of the physical model and enables multiple uses of a process for different units considering different consumption levels. Also, the class of the Batch_parameter contains attributes which describe,
for example, the volume of the batch. The Discrete_recipe describes all possible articles that can be produced on process cells of the discrete manufacturing method and assigns them accordingly. Since different articles usually have different parameters for each unit, this had to be considered in the metamodel. This can be reflected in terms of all Simulation_parameters, such as operating speed, but also the consumption of energy and media. The linking of the respective article with a unit from the physical model is done through the class Link_element, in which all attributes of the respective Discrete_unit can be specifically adapted via a Recipe_id. Thus, the possibility of a global parameterization of a discrete unit, valid for all articles to be produced on it, as well as the specific parameterization with article-specific parameter sets, is guaranteed. In addition, the class Packaging_parameter contains further attributes relevant to the article, such as the packing ratios (see InOut_ratio) and associated dimensions.

4.1.4 | Production plan

The Productionplan_model, as shown in Figure 5, describes the chronological sequence of Discrete_recipes and Batch_recipes on physical plants and thus provides the framework conditions of a metamodel for the simulation of a production system. The Productionplan consists of three sub-models. Attributes with simulation-relevant parameters are also described in the class Productionplan_information. Since a production plant mostly does not operate around the clock, the class of the

FIGURE 5  UML-class diagram for recipe and production plan metamodel
Shiftplan describes the possible working times for each process cell and each weekday. These limit the entire period by the planned nonproduction time. Outside this period, no production takes place. The chronological Sequence of recipes on a process cell is a special feature, as several recipes can be active at the same time. Since a unit can only process one recipe, the time sequence of the recipes plays an important role. The varying time interval between two recipes are represented by a class Matrix with the time intervals as attributes. The equivalent is the sequence of articles, where the time intervals between two articles on a process cell, are caused by changeover and cleaning times. The Productionplan parameter represents the third pillar of the production plan model. In this model, the sequence of recipes or articles assigned by the attribute Sequence_ID is defined in the class Sequence. The assignment is made using the Recipe _ID and the superordinate Process_cell_ID. As a result of the three models in the production plan model, the Simulation_parameter of the source unit of the physical model is parameterized, depending on the framework conditions.

4.2 Development of a modeling solution

The main aspects of the requirements for the software solution result from the identified barriers and challenges for the manufacturing industry, especially for SME, as well as the scientific gap. Thus, they are simple, fast, and context-free modeling possibilities, which do not require any prequalification in the field of modeling and simulation. For an intuitive handling, the software solution should be able to represent the full potential of the metamodel in terms of level of detail of the models and flexibility. As real use-cases and for testing, two different brewhouses for the batch area, as well as returnable-glass bottling plants for the packaging area were modeled in the editor. In addition, the associated recipes, articles and a production plan were also modeled. Excerpts of these are shown in Figures 6 and 7. The developed modeling editor is a platform-independent software and is structured in individual modeling columns according to the metamodel. The modeling editor has a start interface that provides an overview of the model of a production plant and offers the possibility of loading and saving it in form of an XML file. Starting from this interface, models of the four modeling columns can be created. All models can be copied and edited, which simplifies a later experimental procedure during the simulation. The modeling of the physical model is based on the modeling language MES-ML and depicts the plants and machines of the unit level, according to ANSI/ISA S88. The model creation is carried out via block libraries, in which, depending on the areas of batch plants, packaging machines and others, the most common units in the brewing industry are stored. Using the drag-and-drop principle, the blocks can be selected and placed on a modeling surface, behind which a coordinate system is stored. With the help of connections in the form of arrows, the physical connection of the building blocks can be established, partly with the distinction between main product flow and side flow. A further parameterization of the individual blocks is carried out according to the metamodel presented in Section 4.1.1. It is also possible to differentiate whether the respective parameters are global, that is, valid for all articles produced on this unit. Otherwise, an article-dependency of the parameter can be specified and the further parameterization takes place in the article model. In order to offer the greatest possible flexibility with regard to plants and machines to be depicted, the user has the possibility to define blocks himself or to adapt existing blocks. However, this requires deeper process knowledge. Figure 6 shows the physical model of a real returnable-glass bottling plant in the editor, as described in Section 2.1. In addition, another bottling plant, producing PET-returnable bottles, was modeled. The two plants differ on the one hand in the type of machines used and in the installation of the plant, and on the other hand in the articles to be produced. Especially the different types of containers and packaging, but also production types (e.g., new container feed, use of a tunnel pasteuriser, use of a flash pasteuriser or a mixer) for the respective articles could be mapped. In the batch area a brewhouse according to Section 2.1 was depicted. A second brewhouse including an alternative boiling system using a buffer tank, a booster for heating up and a gentle cooking system by using a thin-film evaporator was modeled.

The modeling of a process model is done according to MES-ML, as described by Weissenberger et al. This modeling language is based on the Business Process Modeling Notation. The modeling of the process model is equivalent to physical modeling and represents the structure of the process according to the ANSI/ISA S88. The modeling starts at the process level. To determine the desired sequence of the individual process steps, the start and end must be defined with the help of an element. The processes are linked using connections. This procedure runs through all levels. By selecting a process, for example, it can be deepened and the process stages can be modeled. The selection of elements is made by predefined processes, which are stored in a block library. Since the level of process operations has been defined as energy-relevant, the further parameterization of times
and consumption values is done here. It is possible to extend the process block library at will and thus adapt it to the specific needs of the user. A process operation model always starts with the filling of a unit, followed by a processing part (e.g., heating and resting). After the latter it is emptied. Subsequently “setting up” process operations can be defined. Figure 7 shows the process model on the process operation level for mashing in the editor.

**FIGURE 6** Modeling of a returnable-glass bottling plant for a physical model in the modeling editor (left: block library (dashed); right: modeling surface (dotted)); the parameterization of the machines is carried out by special input masks

**FIGURE 7** Modeling of a process model (process operations for the process stage “mashing” (left: block library (dashed); right: modeling surface (dotted)))
The parameterization of the process operations is carried out by special input masks. For validation different types of mashing processes were modeled. On the one hand an infusion mashing process, just using the mash tun, is modeled by stringing together a sequence of heating and resting process operations. On the other hand, a decoction mashing process, including a mash pan, where a part of the mash from the mash tun is cooked, could be modeled by customizing the sequence of process operations. Furthermore setting-up processes, for example, in the lauter tun, after lautering, like the removal of brewers spent grain and the following rinsing, can be depicted by adjusted process operations, which can take part after the emptying of a unit.

The modeling column for recipes and articles comprises the third column of the modeling editor. This is depending on whether it is a recipe, which links a process of the process model with a process cell of the physical model, or an article, for which packaging machines of a process cell can still be parameterized. Thus, when creating a recipe, all possible batch units of all process cells, as well as all process stages of the processes, are listed and can be linked to each other by marking and confirming. In this way, it is determined for the later simulation which process operations are performed on which unit. Also, the corresponding energy levels, consisting of the consumption data of the process, and the consumption factors of the respective plant, are calculated. This allows maximum flexibility in combining recipes with different production lines. When creating an article to be filled, the parameters for describing the article on the one hand and article-dependent machine parameters on the other hand are in the foreground. To counteract the problem of the numerous parameters required for each packaging unit, multiple optimizations were implemented. For example, by specifying the packaging ratio (e.g., the number of bottles per crate) as well as the container dimensions, the grouping behavior of the units, and the size of the container and container buffer sections are automatically calculated. As different filling articles have different parameters, such as machine speeds and consumption values, due to their containers and the product itself, this must be considered in the modeling editor. For this reason, it is possible to parameterize each unit parameter specific for the current article. Therefore, the same input masks for the parameters as in the physical model are used.

The modeling of the production plan is carried out via the three sub-models as presented in the metamodel. To limit the total time to the plan occupancy time, the working hours for each weekday can be defined in tables for the shift model for each process cell. This data can be taken from the shift plan of the production plant. Outside these times, no production takes place. A production schedule can be defined for each process cell. A distinction is made between production schedules for both areas of the physical model. In the batch production plan, a sequence of recipes that are to be produced on the process cells in the simulation can be created. With the help of a matrix to be defined, which reflects the brewing sequences, the duration between the starts of the individual recipes can be determined. A changeover/cleaning matrix is used to create a production plan for articles. When individual filling orders are created, the number of articles to be produced in the simulation can be varied.

Finally, general information concerning the simulation, such as start and duration, are determined. When determining the start time, the day of the week is also specified. This enables a realistic production plan, as production-free weekends can be mapped. When exporting the model of a production plant, all relevant elements, and parameters are exported to an XML exchange file. To increase the usability of the software, further features were implemented. For this purpose, a help menu was created, which covers all features of the software. It contains explanations about the functionality of the software, all modeling approaches as well as for the specific adaptation of the editor. Additionally, for better error localization and to ensure the correct simulation of the models, an automatic check of the models for correctness and completeness is implemented.

The modeling software developed can be executed in Microsoft Windows runtime environment, regardless of the end device. Mouse and keyboard, but also touch solutions can be used as input devices. Besides the user, the only other interface is the presented XML file. This file is used for export, but also for saving the models. Concerning the required CPU power as well as the main memory, no special requirements are set and can be neglected. The software can be executed by simply starting an executable file, no installation, even of additional software, is required. The total size of the software including all required files is 20 MB. The source code in C++ comprises 43,000 lines. The maintenance and service of the software can be carried out by qualified personnel using the open-source development environment Qt. During the development phase, ongoing verification, as described by Reference [51], of every part of the software solution by several parties took place.

4.3 Validation of the modeling approach and modeling editor

For the answering of the questions in the questionnaire for the validation of the modeling approach and
modeling editor, a German school grading system, whereby a grade of one means very good or full agreement with the question and a grade of six means insufficient or full rejection, was used. The main findings, in particular with regard to the four criteria, are presented in more detail. One of the most important questions regarding the comprehensibility of the modeling approaches is primarily aimed at the metamodel based on the four modeling pillars. The implementation in the modeling approach should make the metamodel easily understandable and comprehensible. Accordingly, the rating of the *Comprehensibility* with an average of 1.8 turns out to be good. The comprehensibility and traceability of the physical and process model were rated “good”, with an average of 1.5. The test persons, who already had previous experience with modeling, also stated that the modeling approach definitely facilitates modeling with regard to simulation and they can imagine using the modeling in the future. The test persons see a need for improvement in the intuitive navigation through the modeling editor (average of 2.25). The modification possibilities of the systems, processes and parameters were evaluated as “good” with regard to speed and simplicity as well as the possibility of article-dependent parameterization. The *Simplicity* of using the entire modeling editor without specific prior knowledge in the field of modeling and simulation of production systems was rated “good” with an average of 1.8. The test persons also rated the *Completeness*, that is, the coverage of an entire production system by the modeling approach, as “very good” with an average of 1.4. Finally, the *Sustainability* of the modeling approach and the modeling environment, that is, the use of the methodology for other production industries, was rated as “very good” with an average of 1.25. In addition to the evaluation of the questionnaire, the XML file created by the test persons was also checked for correct modeling and simulation capability by using the presented check function.

### 4.4 Potential applications of the metamodel and simulation studies

The creation of simulation models for a forecast of the energy and media demand of a production system can certainly be done without a metamodel. Nevertheless, numerous use-cases for simulation experiments describe the necessity of a metamodel. Since the metamodel has a generic and hierarchical structure, existing models can easily be extended and adapted. In case of planned investments, models provided by the plant manufacturer can be implemented into an existing model and the energetic impact on the production system can be verified by simulation in advance. The metamodel also provides the amount of data and parameters required for a simulation.

A precise estimation of the energy and media requirements in advance also plays a major role in the design of the supply facilities. The metamodel supports the mapping of peak loads by means of the defined consumption behavior of the different working units. Especially the avoidance of these peaks, for instance by adjusting the production plan, offers potential for improving energy efficiency. The generic and context-free metamodel allows a flexible simulation regarding the level and depth of the simulation, which depends on the objective of the simulation experiments. Thus, entire production plants or only parts of process cells can be simulated. In addition to a detailed, article- and recipe-specific consideration of a system to uncover optimization potentials and determine influencing factors, the metamodel also allows a global analysis. This is, for the first time, enabled by the metamodel concerning both production areas as well as all types of energy and media. Thanks to the ANSI/ISA-S88 standardization it can be applied to a large number of companies in the beverage industry. This creates uniform comparability and allows benchmarking.

In order to demonstrate the suitability of the modeling approach and the editor, two simulation studies were carried out. The modeling examples described in Section 4.2, a brewhouse and a beverage bottling plant, form the basis of the simulation studies. The time-discrete simulation software “PacSi,” which masters the simulation of packaging processes,[57] was used. The software was extended to the simulation of batch-oriented operation as part of the development of the entire methodology. In addition, numerous functions, such as automatic model generation through the assignment of building block elements, were implemented. A broad base of measurement data, from which the simulation-relevant parameters were determined, was used. The simulation models were generated automatically in a simulation environment and the results were issued numerically and graphically with the aid of specially programmed evaluation tools. The brewhouse of a medium-sized brewery was modeled in the modeling editor with the existing units, including different processes and recipes, and considering a real production plan (see Section 4.2). The goal of the simulation study is to reduce the peak loads of the thermal energy demand by slightly adjusting the times between the individual brews of the recipes (see Section 4.1.4: Matrix, +time). The simulation duration covers a period of 7 days in which a total of 71 batches of three different recipes are produced. Figure 8 shows a section of the comparison between the thermal energy demand curves of the brewhouse before and after the adjustment of the brewing sequences. In the simulation, it was possible to

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**References:**

[57] The brewhouse and the bottling plant were modeled using the simulation software PacSi, which masters the simulation of packaging processes. For more detailed information, refer to Section 4.2. The software was extended to simulate batch-oriented operations as part of the development of the entire methodology. In addition, numerous functions were implemented, such as automatic model generation through the assignment of building block elements. A comprehensive base of measurement data was used, from which simulation-relevant parameters were determined. The simulation models were generated automatically in a simulation environment, and the results were issued numerically and graphically with the aid of specially programmed evaluation tools. The brewhouse of a medium-sized brewery was modeled using the existing units, including different processes and recipes, and considering a real production plan (see Section 4.2). The goal of the simulation study was to reduce the peak loads of the thermal energy demand by slightly adjusting the times between the individual brews of the recipes. Figure 8 shows a section of the comparison between the thermal energy demand curves of the brewhouse before and after the adjustment of the brewing sequences. In the simulation, it was possible to...
reduce the peak loads of the thermal energy demand by 32%, especially for the first recipe.

Furthermore, a returnable-glass bottling plant (see Figure 6) was modeled in the modeling editor. Two filling articles, each with article-specific parameters and a production schedule with a duration of 62 h were modeled. The aim of the simulation study is to investigate the influence of plant availability on the energy and media requirements of the beverage bottling plant. For this purpose, adjustments were made to the MTBF (Failure behavior; \( +\text{mtbf} \)) of the individual units using the modeling editor, resulting in an increase in plant availability of 5% (to 93%). The simulation was carried out with a repetition of \( n = 10 \) trials. In addition to the savings in electrical (4.25%) and thermal (4.01%) energy as well as compressed air (3.11%) and \( \text{CO}_2 \) (6.5%), an accelerated production of approx. 3.5 h (\( \sim 6.4\% \)) was determined as a result of the increase in plant availability. An increased water consumption (5.32%) can be ascribed to the fact that the bottle cleaning machine was in the “Operating” state, which significantly increased consumption, for a longer period of time. Figure 9 shows the course of the electrical energy demand of one simulation run of the corresponding parameterized availability. The changeover and production of the second filling article toward the end of the simulation run can be seen. Production ends noticeably earlier at a plant availability of 93%. Due to the stochastic failure behavior of the individual units and the resulting energy levels, the fluctuating course of the electrical energy requirement results.

5 | DISCUSSION

This publication aims on developing a hybrid modeling approach for the context-free representation of a production plant in the beverage and brewing industry for the prediction of energy and media consumption. Based on this approach, a modeling environment was created, which should allow modeling without specific previous knowledge as well as fast and easy model generation. This should enable SMEs in particular to overcome their barriers and optimize their energy efficiency. The challenge in the development of a modeling approach for the representation of an entire production plant for energy and media simulation is the definition of clear system boundaries and necessary information to be able to make forecasts as accurately as possible later on. Strict adherence to and the implementation of the ANSI/ISA S88 standard, which describes the subdivision of production systems into several pillars, provides the basis for standardized and context-free mapping. In combination with the hierarchical subdivision of the columns, flexible horizontal and vertical model granularity is also enabled. This means that not only the depth of the model, but also the scope of the model of a production plant can be varied. This provides maximum flexibility in the application of the metamodel. In order to evaluate the metamodel with regard to these points, some models have already been created after the implementation in the modeling editor. Thereby the brewhouses of two medium-sized breweries were mapped. The differences are also reflected in changed processes and thus recipes. Two reusable beverage bottling plants with different articles to be produced have also been shown in the packaging area. The possibility of process and article-dependent parameterization of the recipes or articles allows a very precise parameterization of the model. In any case, the metamodel was suitable for mapping all variants and contents the information required for a model to investigate energy and media requirements. This represents the main challenge in model creation, since the data basis in the production plants is usually very small and the development of the
parameters is complicated and time-consuming. The advantage of converting the metamodel created in UML into an XSD is that the XML file resulting from the modeling environment, which describes the model in detail, can be validated against the schema. This means that the schema can be used generically as a check for all created models. In addition, the structure, semantics and data types defined in the schema can be used as an aid for the required mapping in any simulation environment for the automatic generation of simulation models. Up to now, no sensors and interfaces that transfer simulation-relevant data and parameters to the software solution have been connected and implemented. It is conceivable that in the future this will be delivered automatically by machines via suitable interfaces, such as the Weihenstephan Standards, or directly by the machine manufacturers. The metamodel was implemented in a software solution and should offer the possibility to create inexpensive simulation models quickly and easily. Due to the platform independence of the software it can be used on any device. The strict implementation of the metamodel by mapping the hierarchical modeling columns allows context-free and generic hybrid modeling. The modeling environment was continuously verified against the XSD during the development period and after completion it was validated by a systematic test by test persons with respect to the mentioned criteria. The comprehensibility of the models and its representation in the modeling environment was rated as good. This is because models are independent and context-free of each other and are created in the individual modeling domains. The difficulty here is to convey an understanding of the interconnection of the individual modeling pillars. The testers included people who have no previous knowledge of modeling and simulation. The simplicity of the modeling environment was also rated as good. The numerous aids and simplifications within the modeling editor play an important role here. Starting with the help menu, which describes the handling as well as all elements in detail, the function of the automatic checking of models is also an essential point for the easy and fast creation of working models. Furthermore, simplicity is increased by the graphical modeling in the area of the physical model and the process model, based on predefined block libraries. Parameterization is facilitated by, for example, the specification of packaging material ratios and the automatic calculation of the resulting parameters or buffer capacities for different articles. Nevertheless, the validation revealed numerous possibilities for improvement regarding the operation of the modeling editor, which were categorized and implemented accordingly. The completeness of the modeling approach is, especially for nonexperts, a difficult factor to evaluate, as it depends on the specific task. Therefore, clear system boundaries were defined and some use cases were described before the entire methodology (development of a modeling approach and a simulation environment) was developed. This was explained to the respective test persons and they were asked to give an estimation. This overlapped well with those familiar with the methodology and was rated as very good. The determination of the simulation granularity on the unit and process operation level plays a major role. Although coarser modeling would be simpler and much faster, many aspects of a simulation of a production system, such as load peaks in consumption, would be lost. More detailed modeling would provide better simulation results but would require an enormous effort in parameters, which contradicts the requirement of fast and simple modeling. The sustainability criteria describe the generosity of the modeling approach and its application to other production industries and were also rated as very good. The essential prerequisite for this is strict compliance with existing standards, such as ANSI/ISA S88. The modeling editor offers a good possibility to adapt the software solution to other industrial branches by adapting block libraries and easily creating specific blocks.

Furthermore, the simulation studies provided an initial insight into the entire methodology, from modeling to simulation experiments. The case studies show that the metamodel is suitable for representing brewery production plants and forming the basis for an executable simulation model. The challenge here, depending on the complexity, is the parameterization of the models. The simulation studies refer to a detailed and extensive basis of data. In both cases, energy and media savings could be achieved in the simulation by adjusting parameters via the modeling editor. This shows that the modeling approach is very well suited for a fast and simple analysis of plants in the beverage industry. The modeling editor represents the interface to the simulation environment. Simulation models can be generated automatically based on the XML exchange file.

6 | CONCLUSION

It can be concluded that the modeling approach is suitable for mapping an entire production about the simulation of energy and media consumption. The advantages and possibilities of the presented metamodel are:

- Structured, hierarchical, and generic modeling of an entire production system in terms of energy and media requirements.
- Context-free and therefore flexible modeling columns.
- Mapping of batch-oriented and discrete operation as well as dependent consumption behavior in one model.
• Creation of the basis for the data and parameters required to forecast energy and media consumption.

• Application of the modeling approach to other industries by implementing the ANSI/ISA S88 structure.

The suitability of the metamodel was able to be demonstrated by means of use cases as well as simulation studies. A possible solution for SMEs is the developed modeling editor, in which the metamodel was implemented. The context-free modeling in the four modeling pillars is easy to understand and can also be carried out by nonexperts. Graphical modeling with block libraries and numerous aids for the user ensure simple and fast model creation. This could be validated and proven by a systematic test. The structure of the XML exchange file, which is described in a schema file and which represents the result of the modeling editor, allows a favorable simulation model creation since this can be realized in any simulation environment. On the basis of two simulation studies, it could be shown that executable simulation models can be generated on the basis of the metamodel and the energy and media consumption behavior can be represented. Based on the findings, the following objectives can be defined for further work. The authors will present the automatic simulation model generation in a simulation environment in detail. The simultaneous simulation of both operating modes, batch and discrete, at the same runtime will be a novelty. In addition, an entire production system in the brewing industry is to be simulated with regard to its energy and media requirements. The required data basis represents a challenge. A standardized measurement concept and evaluation procedure, considering existing approaches, could provide a remedy and could also be easy to apply. Therefore, the authors will discuss an approach to determine the simulation parameters in both areas of the brewery. To prove the suitability of the entire method, a detailed validation will be performed using real measured data. Furthermore, extensive simulation experiments with a wide variety of approaches, such as the modernization of plants or the adjustment of the production schedule, to reduce the energy and media demand are planned and will be addressed in further publications. The goal of the whole methodology is to create the possibility for a quick and easy analysis of entire production plants in the brewing industry about energy and media consumption and this will offer SMEs in particular an opportunity to optimize their production.

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CONFLICT OF INTEREST

The authors declare no conflict of interests in this research.

AUTHOR CONTRIBUTIONS

Raik Bär: Conceptualization; data curation; formal analysis; investigation; methodology; software; validation; visualization; writing-original draft. Tobias Voigt: Conceptualization; funding acquisition; project administration; supervision; writing-review & editing.

DATA AVAILABILITY STATEMENT

Author elects not to share data.

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REFERENCES

[1] J. Nassauer, Energieeinsparung in der Lebensmittelindustrie. in Lebensmitteltechnologie, 6th ed. (Ed: R. Heiss), Springer-Verlag, Berlin 2004, p. 509.

[2] M. Schlesinger, P. Hofer, A. Kemmler, et al., Entwicklung der Energiemärkte – Energieerfahrungszprognose, Bundesministerium für Wirtschaft und Energie, Berlin 2014.

[3] M. Schröter, U. Weißfloh, D. Buschak, Energieeffizienz in der Produktion – Wunsch oder Wirklichkeit? Energieeinsparpotenziale und Verbreitungsgrad energieeffizienter Techniken 2009. http://hdl.handle.net/10419/29650 (accessed March 13, 2021).

[4] P. Thollander, S. Backlund, A. Trianni, E. Cagno, Appl. Energy 2013, 111, 636. https://doi.org/10.1016/j.apenergy.2013.05.036.

[5] B. Muster-Slawitsch, W. Weiss, H. Schnitzer, C. Brunner, Appl. Therm. Eng. 2011, 31(13), 2123. https://doi.org/10.1016/j.applthermaleng.2011.03.033.

[6] I. Osterroth, A. Holm, T. Voigt, Brewing Science 2017, 70, 89. https://doi.org/10.23763/BrSc17-08Osterroth.

[7] K. Bunse, M. Vodicka, P. Schönleben, M. Brühlhart, F. O. Ernst, J. Cleaner Prod. 2011, 19(6–7), 667. https://doi.org/10.1016/j.jclepro.2010.11.011.

[8] R. Bär, T. Voigt, Food Eng. Rev. 2019, 11(3), 200. https://doi.org/10.1007/s12393-019-09195-y.

[9] A. Trianni, E. Cagno, P. Thollander, S. Backlund, J. Cleaner Prod. 2013, 40, 161. https://doi.org/10.1016/j.jclepro.2012.08.040.

[10] M. Kadachi, Simulationsgestützte Planung und Nutzung von Getränke-Abfüllanlagen. PhD thesis. Garching: Technical University of Munich 2001.

[11] S. Sorrell, A. Mallett, S. Nye, Barriers to Industrial Energy Efficiency: A Literature Review, University of Sussex, Vienna 2011.
[51] H. Balzert Lehrbuch der Softwaretechnik: Basiskonzepte und Requirements-Engineering. 3. Aufl. Heidelberg: Spektrum Akad. Verl 2009. Lehrbücher der Informatik

[52] H. Vonhoegen. Einstieg in XML: Grundlagen, Praxis, Referenz. 7 Aufl. Bonn: Galileo Press 2013. Galileo Press Galileo Computing; p. 2620.

[53] T. Kudrass, T. Krumbein, Rule-Based Generation of XML DTDs from UML Class Diagrams, Berliner XML Tage, Berlin, Germany 2003.

[54] G. Booch, M. Christerson, M. Fuchs, J. Koistinen. UML for XML Schema Mapping Specification. 1999. http://xml.coverpages.org/fuchs-uml_xmlschema33.pdf (accessed: April 8, 2020).

[55] C. Schultewolter. Konzeptuelle Modellierung für modellgetriebene Decision Support Systeme: Konzeption und prototypische Implementierung. Dissertation. Osnabrück 2012.

[56] T. Voigt, S. Flad, P. Struss, Adv. Eng. Inform. 2015, 29(1), 101. https://doi.org/10.1016/j.aei.2014.09.007.

[57] M. Weiß, J. Hennig, W. Krug, Simulative Optimierung von Verpackungsanlagen. in Simulation und Optimierung in Produktion und Logistik (Eds: L. März, W. Krug, O. Rose, G. Weigert), Springer Berlin Heidelberg, Berlin, Heidelberg 2011, p. 185.

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