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An Investigation into Holistic Planning of Urban Factories

Shiva Abdoli [a,c,*], Max Juraschek [a,b], Sebastian Thiede [a,b], Sami Kara [a,c], Christoph Herrmann [a,b]

[a] *Joint German-Australian Research Group, Sustainable Manufacturing and Life Cycle Engineering*
[b] *Chair of Sustainable Manufacturing and Life Cycle Engineering, Institute of Machine Tools and Production Technology (IWF), Technische Universität Braunschweig, Germany*
[c] *Sustainable Manufacturing and Life Cycle Engineering Research Group School of Mechanical and Manufacturing Engineering, The University of New South Wales, 2052, Australia*

* Corresponding author. *E-mail address:* S.abdoli@student.unsw.edu.au

Abstract

Value creation and manufacturing of products is an important part of cities' sustainable development. Urban-Factories allow such value creation within urban areas. Although Urban-Factories might have unintended negative impacts on their neighborhood, mainly environmental impacts, their urban location can offer positive impacts for both the surrounding city and the companies. To achieve these positive impacts, the design of Urban-Factories requires studying other extra aspects, such as urban services and logistics. However, the logistics aspect of Urban-Factories is mostly studied when the decisions regarding other design aspects are already made. Yet, overlooking logistics (or any other aspect) in early stages might lead to losing good design solutions, potentially negatively affecting lifetime performance of Urban-Factories. Therefore, this paper proposes an approach for analyzing the design knowledge of Urban-Factories in a holistic manner, while providing attention to logistics aspects. The practicality of the proposed approach is demonstrated with a case study.

Keywords: Urban factories; Logistics; Integrated planning; Systems engineering

1. Introduction

1.1 Background and problem description

Factories are places of value creation through manufacturing of products and can be found within cities or in rural areas. Production sites can be situated in urban areas as intended "urban factories". These urban factories are intentionally located within an urban area to utilize one or more of specific characteristics of a city, for instance the proximity to customers or utilization of a city's infrastructure. However, unintended urban factories also exist in urban areas, which were originally not planned to operate in a densely populated urban environment and have been reached by a city's growth. Nonetheless, research and interviews with companies producing within cities suggest that there might be benefits resulting for urban factories if certain life cycle phases are implemented in urban factories. This depends on the characteristics of a production system and its surrounding urban area [1]. An empirical study from a city quarter in Sydney, Australia, shows that there is a significant number of production sites located in urban areas [2]. These production sites are interacting and influencing the surrounding city elements and are also being influenced by them in different ways. One example is the required logistics for urban factories that can be implemented as different types. Logistics can play an important role as the interface between the city and the urban factory [3], which allows receiving the resources (e.g. material) to the urban factory and dispatching end-products. Although receiving and dispatching of resources and end-products also exist in not-urban factories, this is a crucial issue for urban factories because it happens in the city utilizing urban infrastructure.

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Design and development of factories and production systems have been studied in the existing literature and resulting in different methodologies [4]. At the same time, the spatial layers of a city can be described with structural models from the field of urban development. Yet, the connection between urban factory with its surrounding area has not been well studied in the existing literature, particularly the operational policies of its logistics have not received its deserved attention. Operational policies in this paper refers to the soft side or control procedures of a process; for instance, three operational policies for a warehousing process can be; First in First Out (FIFO), Last In First Out (LIFO), and First Due Date (FDD). Generally, urban factories are designed or planned by using the existing methodologies for factory design [1]. However, in the design of urban factories, similar to the not-urban ones, the design of logistics operations is developed when the physical design of factory is already finalized in terms of equipment selection and infrastructure design [5]. Such a sequential design approach (first designing the physical aspect of the factory and then its logistics' operations) might lead to facing some unseen problems in the life-time of the urban factories, when the factory and its logistics are dynamically interacting with each other.

1.2 Objectives

With regards to the problem description, it is required to address the factory design and its logistics' operations in an integrated manner (versus sequential). The integrated design in this context allows studying the impact of different design decisions (including logistic operations) on the factory functionality. In engineering design and development, the designers devise models as their artefacts for analyzing activities [6]. Hence analyzing an urban factory requires a conceptual model that demonstrates and embodies its characteristics. In design context, conceptual modelling is defined as the transition from problem situation to model requirements, to a definition of what is going to be modelled and how [7]. Therefore, a first step towards an integrated design is to embody the existing knowledge about the problem situation (urban factory and its logistics) holistically in one model. In this paper, the term 'design knowledge' refers to product description, design requirements, objectives, and constraints.

However due to the broad scale of such a design knowledge, it might be challenging to structure it in a conceptual model holistically [6]. In fact, the broad scale of the design knowledge makes the designers to follow sequential design approaches. Therefore, this paper aims to propose a modelling approach that allows modelling the urban factory and its logistic aspects in a holistic manner. Such a holistic model can improve the designers understanding about the interconnection between an urban factory and its logistic operations, thus minimizes the risks of having design failures or inconsistences in later life cycle stages due to incompatibility between the factory and its logistics aspects. A holistic understanding of urban factories can further lead to enabling the purposeful utilization of specific potentials arising from the location in urban areas for manufacturing companies.

The remaining of this paper is constructed as follows; in the next section, the methodology is presented by application of Systems Engineering principles and Object-Oriented (OO) modelling approach. This paper uses a brewery urban factory to explain its introducing concepts and show the practically of the introduced approach. In last section, the discussion and future directions for this research are discussed.

2. Methodology

2.1 Urban factories characteristics from design perspective

In general, factories (including urban factories) operate based on engineering processes. A brewery for instance performs malt crushing, brewing, fermentation and filling processes in order to transform input material into products. Likewise, the logistic of urban factories include diverse types of processes such as packaging, storing, sorting, and handling. Hence from a design perspective, design of an urban factory involves the designers from different design disciplines. However, each process can perform several internal sub-processes. In other words, the design knowledge of the urban factories is multidisciplinary and large scale with multiple hierarchies. Fig. 1 visualizes the urban factory and its logistics according to this paper scope

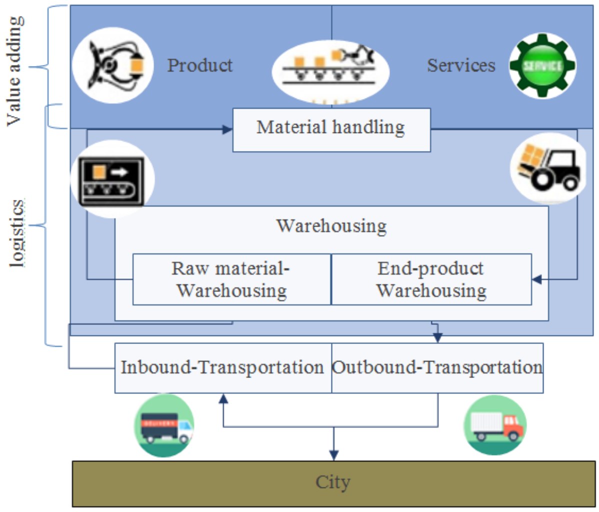

Fig. 1 Cross-cutting demonstration of urban factory and its logistic

Due to their location in cities, urban factories allow the addition of specific activities to their business model, for instance providing certain services for the customers besides producing the main product. Therefore, value adding in the urban factories can happen in two forms; products and services. For instance, a beer bottle is an end-product of a brewery factory. At the same time (and partly enabled by the same equipment) brewing training classes can be offered as a service. Likewise, a tap-room can be provided by an urban brewery factory to the customers combining an on-site sale with an urban social function.

The logistics include the material flow in the factory, from warehousing the raw material, to internal material handling in the factory up to the end-product warehousing. From a design and development perspective, each of the shown elements can have different design requirements, such as type of warehousing or type of the material handling equipment in the factory, which the decisions on the type of operational policies in the warehouses may have impact on material handling and other way around. For instance, if raw material warehouse performs as a cross-dock, the material handling in the factory should be compatible with such a continuous input flow of material, hence a conveyor can be a better equipment choice for material handling compared to the turret truck with a low travelling speed.

2.2 Application of Systems Engineering

Systems Engineering (SE) is an interdisciplinary approach that concentrates on system properties rather than on specific requirements for single disciplines [8, 9]. Hence, this paper uses useful SE principles to provide a foundation for conceptualization of urban factories with regards to this paper objective. In return, application of SE principles can assist in having a multidisciplinary approach where being multi-disciplinary is one of the main characteristics of urban factories. In the development projects by SE application, after requirement analysis, the logical architecture is developed by decomposing a system to certain logical subsystems, which perform certain functions to satisfy the system requirements. Different alternatives can be configured and their goodness is compared against the Measures of Effectiveness (MoE). From a design perspective, conceptual design is considered equivalent to designing the system logical architecture [10] [5]. Therefore from SE perspective, this research focuses on developing the logical architecture of an urban factory such that the architecture embodies the design knowledge holistically. The logical architecture gives an insight regarding how the urban factory and its logistics are interrelated and affect each other, while the architecture provides a foundation for later detail analysis and quantification of the MoEs. To this end, the model of the logical architecture should explicitly indicate the allocation of design requirements to the defined subsystems.

2.3 Application of OO modelling approach

OO modelling is a well-known approach for the design of large scale or complex systems, especially where the systems do not have a single hierarchy [11]. Hence, the OO method can assist in capturing the complexity of holistic modelling of the urban factories. Particularly, this paper uses OO principles and suggests certain architecting guidelines for modelling the logical architecture of urban factories in a holistic manner.

OO modelling approach aims to model a system with certain objects, which have behavior and identity. A class describes a set of objects that share specific characteristics, which an object is a particular instance of a class. Class diagram is one of the most useful and fundamental graphs in OO modelling with the Unified Modelling Language (UML). Class diagram represents a system with its classes, their attributes, and relationship between classes. Therefore, this research develops the logical architecture of an urban factory by modelling its class diagram. Generally, OO modelling of a system can include two main tasks; system abstraction and specific design establishment. Hence, the proposed architecting guidelines are explained through those tasks.

2.4 Abstraction

Abstraction seeks to demonstrate only the critical information of a system and a class can be defined as an abstraction of something in the system. One reason of defining the abstract classes is to demonstrate certain level of similarities between certain elements in the system. Classes can be derived from an abstract class and are called subclasses of the abstract class. Such subclasses can be instantiated and have direct objects. Fig. 2 shows the defined abstract classes for urban factories according to the visualized concepts in Fig. 1. Fig. 2a is the embodiment of explained concepts in section 2.1 with UML semantics. Accordingly, one abstract class is defined for the urban factory and is associated to two abstract classes of logistics and value adding

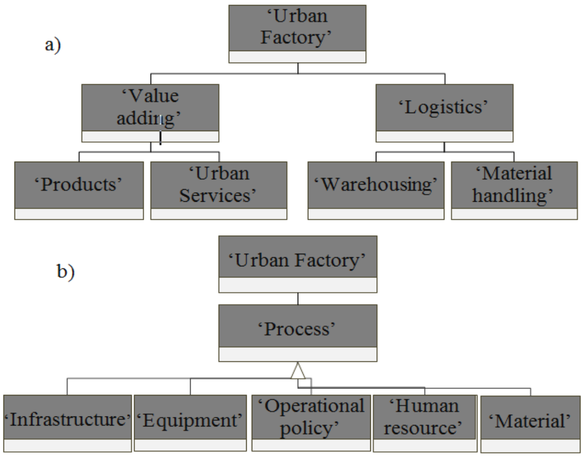

Fig. 2 Abstraction hierarchy of an urban factory a) first hierarchy level b) second hierarchy level

In manufacturing context, the products are produced in certain processes. Likewise, in urban factories different processes cooperate dynamically in order to satisfy the urban factory objectives in terms of producing the products or delivering the required services. Therefore, this paper defines an abstract class to embody the process concept in the logical architecture. Generally, factual processes need certain enablers to make the process function possible. Reviewing widespread literature, the enablers can be categorized into five basic categories; equipment, infrastructure, human resource (HR), material, and operational policy [12-14]. Thus, this paper suggests acknowledging the concept of process enablers as abstract class as well. Defining different types of enablers satisfies having a multi-disciplinary approach in the developed logical architecture of an urban factory.

2.5 Specific design

The introduced abstraction in Fig. 2 demonstrates the common elements of urban factories on a high-level to capture similarities. However, real factories as actual implementations differ in their specifications, particularly in terms of performing factual processes. To address the factual processes, subclasses should be derived from the process abstract class equivalent to the specific factual processes. For instance, if a brewery factory includes malt crushing, brewing, fermentation, lagering, and bottling, five equivalent subclasses should be derived from the process abstract class. This applies to warehousing processes and material handling as well. Hence, unloading raw material, storing, picking, handling to the malt crashing area, handling bottles to the warehouse, and shipping can be defined as the required processes for warehousing and material handlings activities.

However, all the value adding activities of an urban factory might not need all the processes. For instance, the taproom service requires certain processes (mainly tap room process) but not necessarily the warehousing processes. Therefore, in the first step subclasses should be derived from the product and service abstract classes equivalent to the factual products and services that an urban factory provides, these subclasses are called value adding subclasses. Then they should be associated to their required subclasses of processes. This also demonstrates the interconnections between the existing processes. Moreover, defining such a relation embodies the value creation in the logical architecture of an urban factory.

From the design perspective, planning for factual processes may belong to different disciplines. For instance, planning for a material handling process is different from the design of a bottling process. Accordingly, processes may require different types of enablers. Therefore, a subclass that is equivalent to each special enabler type is needed to be derived from the corresponding enabler abstract class. Each enabler subclass shows a special type of the enabler, which the special type is different from a specific enabler. For instance, the handling equipment is a special type of equipment, yet 'Forklift', 'Conveyor', and 'Turret truck' are three different specific enablers. Therefore, each process can be associated to its needed enabler's types (in this case handling equipment and not Fork lift; Conveyor or Turret truck). Fig. 3 shows the relation between the defined subclasses of equipment and the processes, which such a relationship should be applied between processes and other enablers as well. Not all processes need to have all types of the defined enablers. For instance, the fermentation might not need infrastructure as its enablers. It is worth mentioning that two processes may require similar types of enablers, but they may be planned differently. For example, these processes; handling to the malt crushing area, handling Work In Process (WIP) in the factory, and handling bottles to the warehouse (input handling, WIP handling, and bottle handling), require handling equipment. Hence, they all are connected to the same subclass of handling equipment. Yet, one may use conveyor while the others use forklift. Following the introduced approach, the logical architecture can clarify the required enabler type for different processes. However, the decision regarding selection of specific enablers is carried out later.

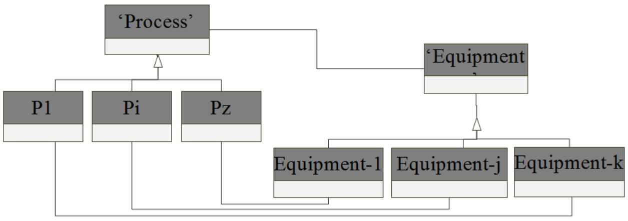

Fig. 3 Relation between subclasses of processes and enablers

Different enablers may have different design requirements (belonging to different design/planning disciplines). For example, the required infrastructure for the unloading process (as one process in the warehousing) can be a dock, which has 'dock position' as a design requirement. The dock position is a critical issue when the factory and its warehouse are located in the urban area due to roads accessibility and safety concerns. On the other hand, the brewing process requires specific brewing equipment, which has different design requirements such as its capacity. Storing and picking processes have important design requirement regarding storage and picking operational policy, which the decisions about them clarify the warehouse type in terms of being a cross-docking warehouse or act as a replenishment center for the factory. This research proposes addressing the design requirements as attributes (design attributes) of corresponding enabler subclasses (multi-disciplinary approach). However, due to complexity of some design requirements, objects can be associated to the design attributes in order to serve the complex structure of the design requirements, which are termed Design-Objects in this paper. MoEs can also be defined as attributes of the subclasses, such as cost as or environmental impacts as two important MoEs in planning and development phase of an urban factory. Following this approach, a process can have any type of physical or operational enabler. Thus, process concept in this approach covers a broad range and is not limited to the transforming of material or energy. Hence, this approach provides a valuable basis for integrating the urban factory functionality with its required logistic and particularly its operational policies, which belong to different disciplines but together can realize the intended functionality of an urban factory [15].

3. Results

A design alternative is the materialized form of the logical architecture. In the developed class diagram, the subclasses of the enablers carry the design requirement (or the decisions that are needed to be made in the planning phase of an urban factory). Hence, an enabler subclass can be materialized by allocating proper Design-Objects to its design attributes. Allocating different Design-Object to the design attributes contributes on generating a set of different system alternatives for the urban factory, which conform to the logical architecture. For instance, one alternative is configured by dock position in the middle, conveyor as the equipment for input material handling and forklift for bottles handling.

Another alternative is configured with the only difference on employing turret truck for input material handling. In warehousing industry there are two possible options as operational polices to store the products in the storage area; Class Based Storage (CBS) and Random. The former stores a product in a predetermined storage location to ease picking the products later and shortening the operator time to search for the products. Whereas the latter allocates the products to the first available spot. Therefore, two possible alternatives can be configured while they vary in their operational policy to store the products in the warehouse; one with CBS and the other one with random policy. However, if the warehouse is supposed to work as a cross-dock, then application of random operational policy may conflict with a cross-dock warehouse; because it requires high pace picking of the products which is not very compatible with random operational policy.

Therefore, it can be said that an alternative can be developed by instantiating the class diagram. In this research, the developed logical architecture can represent the Meta-Logical-Architecture of an urban factory such that the alternatives are instances of the Meta- Logical-Architecture.

From the SE perspective, the defined classes along with their relationship can represent the logical architecture of an urban factory in terms of the system decomposition into its subsystems and their structural relation. Considering the specific aspects of urban factories the proposed approach allows coping with the increased complexity arising from the urban location. The implementation of urban-enabled services can be integrated into the design process and connected to the holistic factory design. The generation of design alternatives by instantiating enables the systematic combination of value-adding activities for urban factories that is currently mostly undertaken based on intuition of operators and planners.

4. Demonstration case

The data of the brewery factory is given in Table 1 and some aspects of the case study are already explained in the methodology section. The factory is of rather small size and needs to produce 21,000 bottles monthly. According to the introduced modelling approach, the logical architecture of the brewery urban factory is developed and demonstrated in Fig. 4. Due to space limitation and confidentiality, some details are not shown. Fig. 4 shows several planning modules for different aspects of the factory, for instance the warehouse class embodies a complex system that includes different processes as discussed in this paper [16]. The shown warehouse class can be handed to the warehouse managers to plan the warehouses and communicate their planning approach by allocating Design-Objects to the design attributes. Hence, this approach allows having multiple levels of hierarchy. The same applies to the material handling and the entire brewing processes, while this model-based communication reduces the risk of miscommunication in multidisciplinary developments. Finally, the fully materialized class diagram demonstrates a coherent picture of the urban factory with all the made decisions for the design requirements. At this point, generally the system engineers who have a systematic view can integrate all the individual decisions and analyze the feasibility of the entire planning.

Table 1. Case study data.

Specification	Urban factory	Not-Urban factory
Raw material shipment	14-20 days	14-20 days
Raw material warehouse space	200 m^2	200m^2
End product shipment	10 per week	One per week

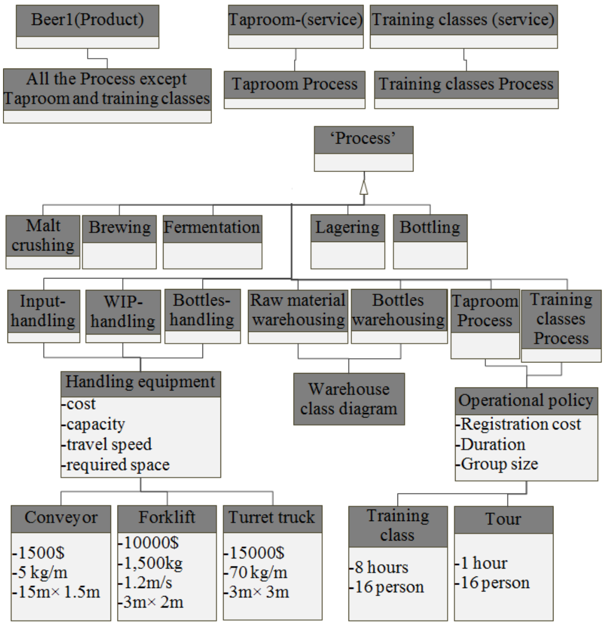

Fig. 4 Logical architecture of a brewery factory

The defined MoEs for the subclasses of enablers allow an early comparison between different alternatives. For instance, there are two possible alternatives, which one uses conveyor and the other uses forklifts in the input material handling. In the first alternative, the given dimension in the conveyor sub-class (15m×1.5m) is enough for a smooth material flow in the factory and satisfying the required throughput (21,000 bottles monthly). For the second alternative, three forklifts are required, which cost more. From the view point of the material handling discipline, the conveyor might seem a better choice. However, the forklifts require less space, which lead to lower total cost when space cost is also taken into account. Moreover, forklifts give more flexibility with regards to the interaction with warehouse as well. This approach allows attaining some insight regarding the existing trade-off between different logistic decisions and how they impact the urban factory performance.

Some training classes can be offered to the public, which the required implementing processes are defined for the brewing training classes. These processes require an operational policy determining the registration cost for participants, the duration of the course and the group size. As the brewing classes are taking place in the taproom and production area, the equipment of these processes are utilized for the brewing class as well. When generating design alternatives by instantiating the abstract classes, different combinations of services will result and can be compared regarding their financial benefit. These alternatives can help to identify feasible value-adding services and to allow not only to compensate the higher costs of producing in a city but also to create new fields of income for urban factories.

The location of the brewery factory implies certain constraints to the explained material flow (see Fig. 1), such as limiting the available time window for receiving/dispatching into and from warehouse or put pressure on minimizing the warehouse size due to high space cost in the urban area. The space cost in the urban area is almost double of the industrial area. The warehouse managers might plan the warehouse according to the available time window, which does not allow continuous flow of raw material to the factory. In the same time, the factory designers might plan the factory by considering a continuous flow of material and end products from and to the warehouse by using the conveyors as the main material handling equipment. However, this planning would lead to a conflict in later stages, because a continuous flow of raw material cannot be realized under these constraints. This example shows the importance of having a holistic planning perspective for urban factory development. By having this holistic conceptual model, the system engineer can easily identify such conflicts in early planning stages. Moreover, when warehouse managers and factory planner have access to such an integrated conceptual model, they can realize the possible impacts of their decisions on other aspects of the urban factory as well.

For this case study due to the nature of brewery industry in terms of the lifetime of its raw material and shipment size requirements, the raw material warehouse should have a similar size in case of urban or not-urban factory development. However, the bottle warehouse can have large scale with less frequent shipments for the not-urban factory because of cheap space cost; respectively the size of bottle warehouse in not-urban and urban factory is roughly calculated as 960 m^2 and 120m^2. As a result, the material handling batch size can be larger in the not-urban factory (96 bottles), whereas in the urban factory the batch size should be smaller because of higher pace of material flow (24 bottles). Accordingly, a cost calculation is performed, which the results show that the same factory in urban and in not-urban area should have different logistics for cost minimization. For instance, due to smaller batch size in the urban factory, the forklift is a better option, while turret truck performs better in the not-urban factory. On the other hand, the total material handling cost (including warehousing cost) is higher in the urban factory due to several reasons such as space cost, frequent shipment, more WIP handling in the factory and so on. Yet, the value adding services from the urban factory can compensate such extra cost and lead to higher revenue for the urban factory. In this case, revenue is a MoEs and is embodied in the logical architecture.

5. Conclusion

The results show that this approach can greatly assist to capture the complexity of modelling the urban factories in a holistic manner. The paper proposed to hierarchically abstract the urban factory to certain abstract classes that allowed having a multidisciplinary approach in the planning stage of urban factories. The developed logical architecture can embody all the design requirements, including the factory, its logistics and particularly its operational polices. As a result, the relation between the different decisions regarding the choices of design requirements can be understood better. However, it is necessary to quantitatively model such relations and their possible impacts on the urban factory objectives fulfilment. The presented approach allows broadening the analysis scope from the urban factory logistics itself to other related planning decisions, for instance employee transportation. In this case, different alternatives can be configured in terms of the providing parking area for the employee, which can be compared from different perspectives such as cost or imposed traffics to the surroundings. Considering the complexity and interactions with their environment of urban factories, application of agent-based simulation can be beneficial, which is one of the future research directions for the presented work.

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