Proceedings in Manufacturing Systems, Volume 11, Issue 2, 2016, 63–70 ISSN 2067-9238

ENGINEERING FOR LOGISTICS

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Abstract: *This paper introduces a specific and customized approach on engineering for logistics. By deriving several new methods it is shown how they perform on various engineering tasks and material handling equipment. A special focus is on the reuse of the methods and on their identifying process. An interactive 3D-model to depict and identify the impact of the methods concludes the paper. Containing a large collection of literature the reader is able to further develop the methods introduced here for his personal use. The paper summarizes some essential parts of a Habilitation Thesis at Graz University of Technology.*

Key words: *engineering methods, product development, logistics engineering, material handling equipment, CAE, Physical Internet.*

1. INTRODUCTION

Engineering is a broadly used terminus in different activities of mechanical engineering. From one industrial sector to another nearly anybody developed own and customized approaches and methods to fulfil engineering tasks. Focussing on design engineering one must take a closer look to various disciplines to identify differences therein.

An industry of interest is the logistics one. Several actual (Mega) trends force producers to deliver more customized products in less time than ever.With an annual volume-increase of more than 7% [12] logistics is one of the fastest growing industries nowadays. Aware of that trend, manufacturers of material handling equipment have to cover this and provide more powerful machinery in fast cycles.

But engineering in logistics isn't that highly performative and well developed as in other sectors (i.e. the aerospace and automotive industry is used to handle many challenges for years that are arising in logistics engineering actually). Besides that material handling objects (the machinery within logistics) are broadly various, logistic machinery is nearly ever a customized single installation for one special use-case. This would arise the idea that highly performative software products and methods are used to handle complexity within this sector. The following work describes, that there is a lack of qualitative engineering but a necessity therefore. The paper summarizes essential parts of a Habilitation Thesis at Graz University of Technology [15].

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2. GAPS BETWEEN LOGISTICS ENGINEERING AND OTHER INDUSTRIES

2.1. Trendsetter industries and engineering – state of the art

It is one main idea of the following work (and mainly [15]), to take a look to automotive/aerospace, how challenges are handled there, assuming that many engineering methods in the past arose from demands in this industry. I.e. the development of CAD started with the development of the Mirage airplane in the late 1960ies, simulation was used in various vehicle areas to allow broader testing and save time in development.

Table 1 will later identify most useful methods from trendsetters for logistic (mechanical) engineering showing a gap with the industry.

2.2 Characteristics and assumptions for logistics engineering

Sources are necessary to prove assumptions that logistics engineering and its design work is different to other industries. Therefore 16 years of personal experience in logistics engineering with more than 40 different companies is provided in [15] joined by a literature review and experiences from large trade fairs. Combining with a vital scientific exchange it merges to assumptions for logistic engineering, depicted by their importance (font size) in a tag-cloud (Fig. 1). It shows an actual stage how mechanical design engineering work is done in logistics, representing a synergy of the sources mentioned.

One of the main issues with automotive/aerospace compared to logistics engineering is a lack of special methods for logistics engineering and a use of engineering methods in general. Methods are not reserved to scientific work for proving righteousness. Using methods, daily work can be done more accurate and faster with a great benefit in their re-use. Identifying and developing methods, useful for logistics engineering the same way as those developed in and for automotive/aerospace, must be done accordingly to cope with nowadays challenges (Chap. 1, 2).

Before deriving methods for logistics engineering a closer look has to be done on material handling equipment – the logistic objects. Those objects can – according to system-theory – be classified into four size-dimensions [13] and more detailed in [15]:

1. Logistic systems;
2. Material handling machinery;
3. Machinery subsystems and assemblies;
4. Components of machinery.

Therefore it becomes obvious, that completely different methods and engineering approaches have to be taken into account for these sizes. Where Logistic systems are mainly engineered by logistic planning (so called layouting) from material flow and storage demands, the other objects are part of common mechanical engineering approaches.

3. FINDING AND DEFINING METHODS FOR LOGISTICS ENGINEERING

To not only perform a snapshot of useful methods for today a process has been developed, how these methods can be derived systematically in future with new assumptions and new challenges. It has been introduced and used in [15] and is depicted as an overview with Fig. 2. Obviously it's a scientific requirement to clearly show how results are created; the process therefore shows this for methods for logistics engineering.

The process of identification delivers an approach with three action areas that are depicted in Fig. 3 using the underlying assumptions from Fig. 1. Basing on the identified gap between automotive/aerospace and logistics engineering (Table 1) it results in currently 10 methods [15]. Three of them are introduced in Chap. 4.

With knowledge-management as an overall dimension of application two more core areas from design engineering and calculation/simulation are addressed with the methods. As knowledge, its use, re-use and storage is important in nowadays challenging design work (Chap. 4.3) knowledge-management touches and encapsulates all engineering dimensions (Fig. 3).

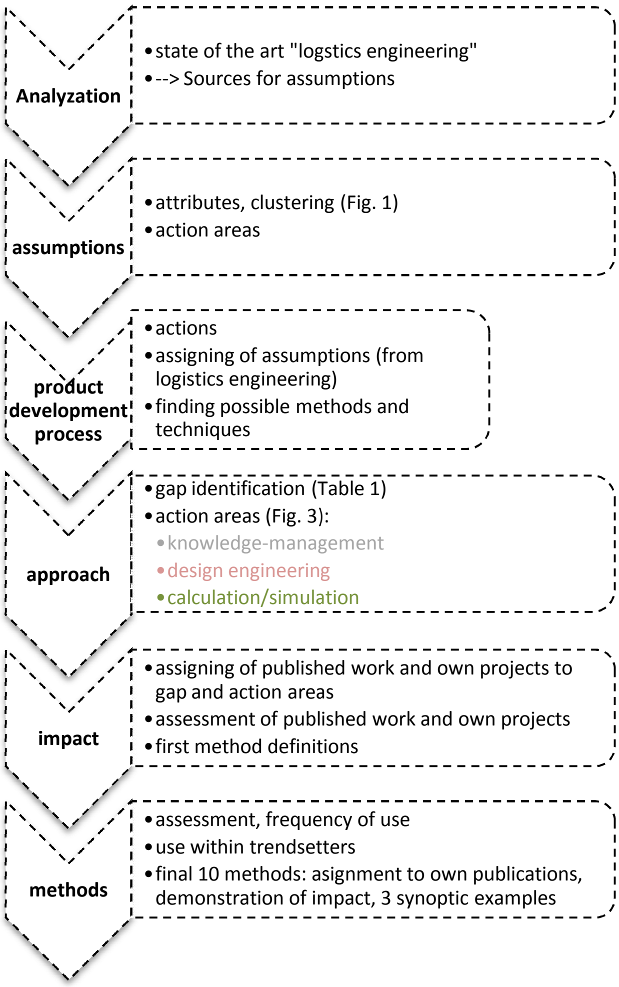

Fig. 2. Process to identify suitable methods.

Fig. 1. Assumptions for logistics (mechanical) engineering.

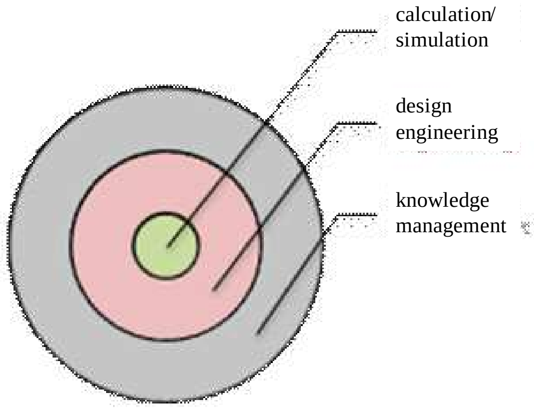

Fig. 3. Application/action areas of logistics engineering.

Table 1

Gap between product development and logistics engineering – action areas

Assumptions for logistics engineering	**Facts (i.e. trend-setter like auto-motive/ aerospace)**	**Approach:** *colours of action areas see Fig. 3*
Specific solu-tions	Product program	Parallel approaches logistic planning/ layouting and design, knowledge reuse – simultaneous engineer-ing
2D-CAD (in layouting and design eng.)	High-end 3D-CAD	
Long product lifecycles	Short product lifecycles	Design methodology and methodic CAD
Variants from adapted projects	Configuration and modularization	
Development in projects	General F&E	Assessment methods. Design automatization for variants without specialists
Product manag-ers do design work	Specialists in multiple domains	
Field testing	CAE and virtual development	CAE for logistics. Securing CAE-quality for non specialists
Less standards	Approved standards	
Empiric detail knowledge	Systematic detail knowledge	Transfer of approved methods (standards), CAE-libraries and workflows
No CAE for standards	Standards with CAE-knowledge, broad range of validity	
Knowledge storage in projects	PDM, expert sys-tems	Knowledge manage-ment (different classes), KBE and KBx
Small engineer-ing development areas	Connected special-ists in various domains	
Specific offers	Defined product program	

4. METHODS FOR LOGISTICS ENGINEERING

4.1. Design methods – requirements engineering for logistics[2]

Within engineering design work each product is part of a product life-cycle (i.e. according to [8] and Fig. 4). Within logistic engineering products are not only single machineries but much more large systems and collections of different machineries which are assembled to systems (i.e. distribution centres, sortation centres or production warehouses). Therein not all products are completely new design and in logistics engineering there are often long product life-times and only slightly adapted con-struction with fixed function principles. According to [1, 3] one can differ between three different kinds of design – it will be used to assign appropriate methods to different activities with logistic objects of different sizes:

- *new design*: completely new function principles;
- *adapted design*: re-use of function principles with new geometry;
- *variant design*: adaption in geometry;
- (repeated design).

Logistic design engineering is strongly connected to layouting activities which has to fulfil customers logistic boundaries about material flow rate and storage capacity.

[2] Requirements engineering here means merging logistic layouting with engineering design task definition in an earliest stage of logistic system design. It’s therefore different to the requirements engineering in literature.

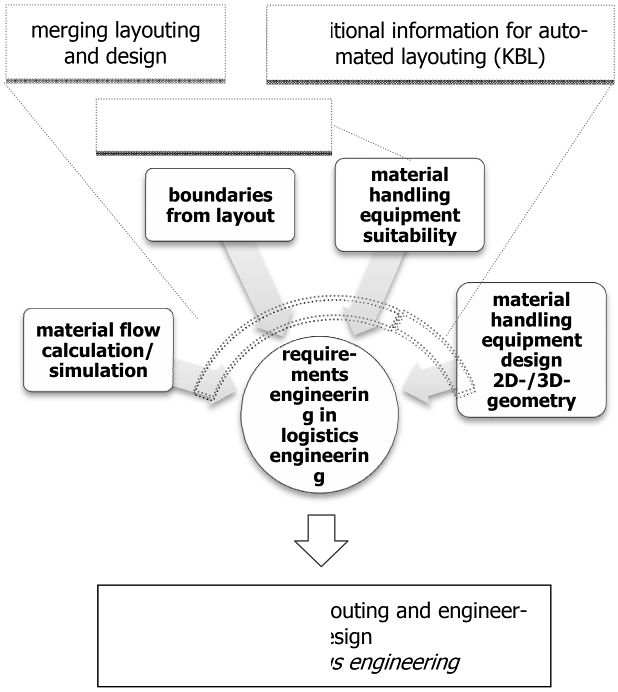

Fig. 4. Requirements engineering in logistics engineering – types of boundaries.

This layouting process is not done by design engi-neers and is always the first step in designing new logis-tic systems.

So one can easily identify, that there is much poten-tial for misunderstanding and much coordination action between logistic layouting and design engineering which is at least time consuming. Fig. 4 depicts types of boundaries that have to be considered in designing new logistic systems.

If a standardized product development process is taken into account it can be viewed in parallel with stan-dardized layouting processes according to Fig. 5. Starting requirements engineering for design work the earliest way it will lead to a simultaneous engineering approach between layouting and design.

Many methods and procedural engineering ap-proaches are necessary to handle this complex aggrega-tion of engineering work. Besides the three other meth-ods that are introduced in [15] like:

- methodological engineering development.
- automated generation of function structures,
- methodological CAD,

mainly the knowledge-based engineering approach (known as KBE) is useful for a simultaneous engineering approach for logistic requirements engineering – merging layouting and design. It is part of an extension of design automation and introduced as KBx [7] (for handling knowledge within KBE see also Chap. 4.3).

Design automation in various stages and ranges (de-tails in [7]) can help to early build variants in layouting without too much design knowledge necessary. The Knowledge-based layouting (KBL) allows an automated arrangement of intelligent 3D-objects in a typical 2D-layouting environment and provides the necessary infor-mation for further detail design like geometric bounda-ries, bills of material. So with KBL in an early stage one can easily build variants that are much more able to provide crucial information for suitable offers to customers. The saved time for development is much useful for further engineering design, and faster offers will lead to more satisfied customers[3].

4.2. Simulation methods – logistics engineering simulation library

Those highly performative products defined by logistic layouting and engineered by mechanical design engineers do not only need a kind of empiric performance-proof by tests but the more calculation and simulation. There are hundreds of different calculation and simulation approaches in engineering. According to [16] one can differ calculation methods in three classes:

- *A-methods* (academic): program languages (mathematics) and adapted B-methods;
- *B-methods* (bridge): stand-alone specialized software (i.e. Multibody-Simulation, FEM);
- *C-methods* (common): CAD-embedded CAE or easy-use empiric calculation schemes.

Between all those methods it’s the challenge, to choose the appropriate one. Therefore one has to keep in mind all issues about installation/operation effort, finances, skills for operation, continuous training and use. So not every time the most powerful system is the right one for a calculation task. [15] provides selection criteria and processes to identify the right simulation solution in logistics engineering. It assigns kinds of design (Chap 4.1) to the stages in the product development process (Fig. 5) and suggests methods or typical logistics engineering simulation tasks like: structural behaviour, dynamics and visualization. With the main simulation focus assigned from: fatigue, NVH, (topological) optimization, functional optimization and safety issues the user can choose from many different literature sources and concrete simulation products accordingly.

A standardized iterative process how simulation activities within A-, B- and sometimes C-methods can be performed is depicted in Fig. 6.

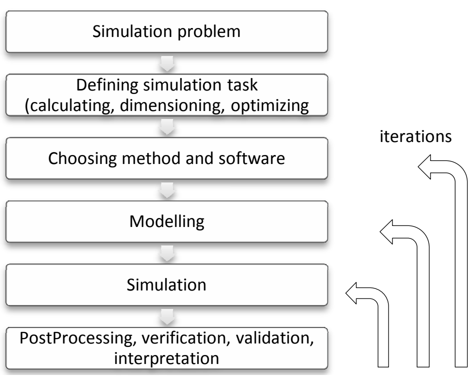

Fig. 5. Steps in simulation procedure.

[3] Details on implementation effort of KBL-solutions for different logistic systems are also object of further considerations and can be found in [13].

Selected KBL-solutions are implemented yet for AS/RS and sortation loops and can be found in [5], [13] and with [14].

Technical details concerning the KBL and KBE methodology are within the KBx-Method in [15]. Details concerning KBSD can be found at [5].

Table 2

Simulation library for logistics engineering [17]

Level	Modell -function principle	Simulation domain
basic function	Interaction of loading devices with var. conveyors	MBD, flexMBD
	Behaviour of parcels	MBD, DEM(*) 22]
	Wire ropes	FEM, MBD and signalflow [18]
	(Flat)Belt drives and conveyors	MBD
	Chain drives	signalflow and MBD
	Tooth belt drives	Signalflow
sub-system	Carousel system drive	signalflow [21]
	Infeed of parcels on sorters	signalflow and MBD [2, 4, 5, 19]
	Discharge of parcels from sorters	MBD [6, 20]
	Discharge of loading devices from conveyors (var. principles)	MBD
	AS/RS drive: tooth belt drive	signalflow [20]
	compressors for tire repair	MBD, flexMBD [9]
	Tilting arm gripper (AS/RS)	Signalflow [23]
	Sorter drives	MBD
	Sorter dynamic behavior (wheel-rail)	MBD
	Crawler drives	MBD, flexMBD
System	Chain hoist (with cranes)	signalflow and MBD [24]
	Overhead transmission	signalflow and MBD

As introduced in Chap. 2 there are no simulation specialists or fields of calculation experts in logistics engineering. Therefore design engineers have to do all calculations and simulation activities there selves. Running the risk, that not every design engineer is a simulation expert one has to re-use and provide secure knowledge. Work [15] and Chap 4.3 partly introduce ways and methods therefore. Table 2[4] shows existing simulation libraries and their sources for sub-model-technique and easy and secure reuse of validated sub-models.

4.3. Knowledge methods

As introduced in Chap. 3 knowledge, its use, re-use and storage is important in nowadays challenging design work and knowledge-management touches and encapsulates all engineering dimensions (Fig. 3). Here the same question arises than with calculation/simulation: how to choose the appropriate method with appropriate effort in implementation, use, administration and training. Especially with KBE and KBL much knowledge is explicitly stored in CAD or other software environments – hard to manage and expand. All modern findings concerning knowledge-management in engineering (VDI 5610 [25]) ague that if engineers see an (even not very large) additional effort in managing a knowledge-management tool

[4] MBD is multi-body-dynamics with simulation (MBS) in different simulation software.

It is different to the signalflow-approach where physical structures and objects are idealized abstractly mainly by there driving equations (like MATLAB.Simulink, SimX With Modelica,…). Multiple simulation domains are united more powerful here than in MBS(i.e. coupling hydraulics, electrics with mechanics and control).

FEA is the finite-element-analysis. Nowadays integrated in most CAD-systems available in many different physical domains.

DEM is for Discrete Element Method which represents parts as small spheres, useful in simulating bulky goods.

and not being aware of its benefit, they will not support but even block its use! So the challenge lies in providing methods being simply enough to perform well and not to over-stress users.

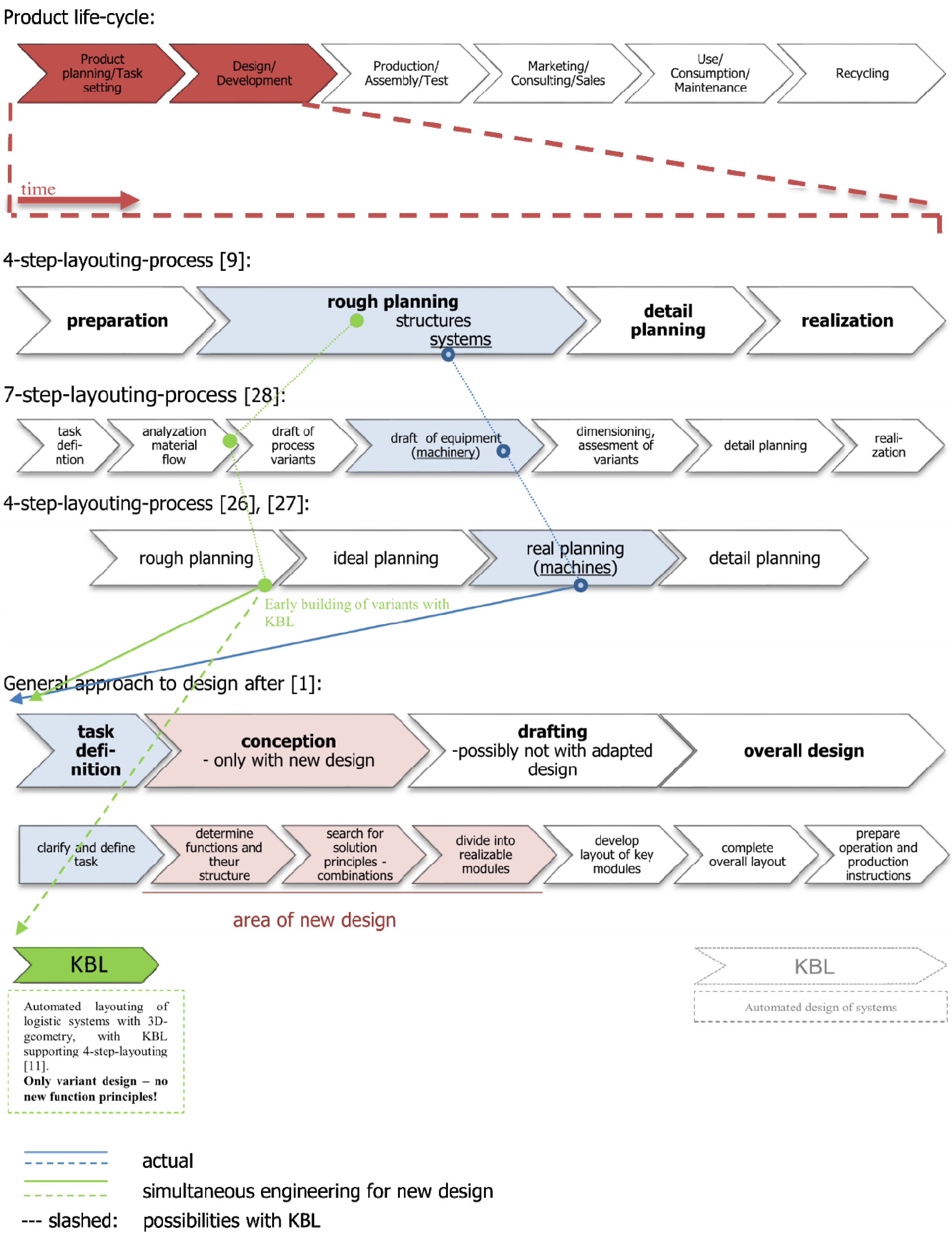

Fig. 5. Layouting and design processes – simultaneous engineering.

Work [15] therefore introduces several easy-to-use knowledge-management methods (for personal and team use) where a selection therefrom is presented here (partly from [25]):

- Design catalogues: are well-established engineering tool providing static knowledge storage (i.e. in [3]).
- Calculation tools: are broadly used and mostly empirically derived sometimes as standards. Integrated in software they are containing implicit knowledge.
- xKBE-app and method: provides a software-app and workaround to handle, derive and store knowledge from KBE and KBL solutions (see [7 and13])
- Semantic networks and Ontologies: closing a gap between natural, formal language [15].
- Mindmaps: support human thinking processes by graphically providing knowledge.
- Taxonomies: are also graphically oriented but hierarchically organized knowledge-displays.
- Wiki-systems: are commonly known and allow collaboration in storing and developing knowledge.
- Matrix methods like DSM, DMM: try to visualize and derive dependencies in complex product structures.
- Euler diagrams: try to solve a problem with hierarchical knowledge representation (Taxonomies).
- Complexity software (like LOOMEO®): assists in complex product structures to derive dependencies and configurations.

Main functions and parts of the knowledge bases indicated above are depicted in Fig. 7. Fig. 8 helps to identify suitable knowledge-methods in design engineering tasks by assigning methods to knowledge activities and general goals displayed over the product development process.

		fullfilling			
		create knowledge	store knowledge	distribution of knowledge	application of knowledg
design cat.	Design catalogues		+	•	•
calc. tool	Calculation tools		•	•	+
xKBE-	xKBE-app and method	+	+	•	•
SemN.	Semantic net	•	+	•	+
Ont.	Ontologies	+	+	+	+
MiMa.	Mindmaps	•	•	•	•
Tax.	Taxonomies		•	•	
Wik	Wiki-systems	•	+	+	+
Matr	Matrix methods like DSM, DMM,…	+	•	•	+
Euler	Euler diagrams	•	•	•	•
Loo.	Complexity software (LOOMEO®)	+	+	+	+

+	good
•	appropriate
	not useful

		part of knowledge base			
		terms	attributes	magnitude	relation
design cat.	Design catalogues	+	•	+	
calc. tool	Calculation tools			•	+
xKBE-	xKBE-app and method	+	+	+	+
SemN.	Semantic net	+	•	•	+
Ont.	Ontologies	+	•	•	+
MiMa.	Mindmaps	+			•
Tax.	Taxonomies	+			•
Wik	Wiki-systems	+	+	+	•
Matr	Matrix methods like DSM, DMM,…	+	•		+
Euler	Euler diagrams	+	+		•
Loo.	Complexity software (LOOMEO®)	+	+	•	+

+	full
•	partly
	not covered

Fig. 7. Functions of knowledge instruments for logistics engineering.

approac to design with VDI 2221 [1]	phase	task definition	conception		drafting		overall design	
	stages	1. clarify and define task	2. determine functions and theur structure	3. search for solution principles - combinations	4. search for solution principles - combinations	5. develop layout of key modules	6. complete overall layout	7. prepare operation and production instructions
	results	specificatoins	function structures	principle solutions	moule structures	preleminary layouts	definite layouts	product documents
kind of design	new design							
	adapted design							
	variant design							
	repeated design							
methodological use of knowledge								
challenge	activity							
core activities with knowledge	create knowledge	SemN., MiMa., Tax., Matr., Euler	design cat., , MiMa., Wik.		design cat., calc. tool, SemN., MiMa., Wik.		xKBE-app, SemN., Ont., Wik., Matr., Loo.	
	store knowledge	SemN., MiMa, Tax., Wik., SetVis.	design cat., SemN., Tax.		calc. tool, SemN., Ont., Matr., Loo.		calc. tool, xKBE-app, SemN., Ont., Wik., Matr., Loo.	
	distribution of knowledge	SemN., MiMa, Wik.	design cat., Tax., Wik.		calc. tool, SemN., Ont., Matr., Loo.		calc. tool, xKBE-app, SemN., Ont., Wik., Matr., Loo.	
	application of knowledge	SemN., MiMa, Wik.	design cat., SemN., Wik.		calc. tool, SemN., Ont., Matr., Loo.		calc. tool, xKBE-app, SemN., Ont., Wik., Matr., Loo.	
	for multi-activities	SemN.	design cat.		Ont.		xKBE-app, Ont.	
knowledge management for:								
powering effiiency								
manage complex product structures								
work with collaboration and distributed teams								
documentation								

Fig. 8. Assigning Knowledge instruments to development stages in logistics engineering tasks.

5. IMPACT ON MATERIAL HANDLING EQUIPMENT DESIGN – THE PHYSICAL INTERNET M-BOX

The Physical Internet tries to arrange and manage physical objects like digital data in the internet. Therefore special machinery and equipment is necessary. Especially the interconnection of single load units to unit loads is a crucial KPI, wherein the MODULUSHCA-project developed the M-Box at Graz University of Technology [10]. This first M-Box prototype is able to encapsulate goods (mainly FMCG [5]in retail) like digital information within e-mails is encapsulated. All physical goods flow is attended to become self-organised with large IT- and logistic-systems empowering it.

The M-Box is a high sophisticated piece of modern engineering (Fig. 9). Its engineering development used different methods with different intension:

- Simultaneous engineering (Chap. 4.1) and methodological design engineering.
- FEA for virtual box strength tests (Chap. 4.2, process according to Fig. 6).
- KBE and Knowledge management for modular design variants; more than parametric CAD (Chap. 4.3: design catalogues, calculation tools, Mindmaps).

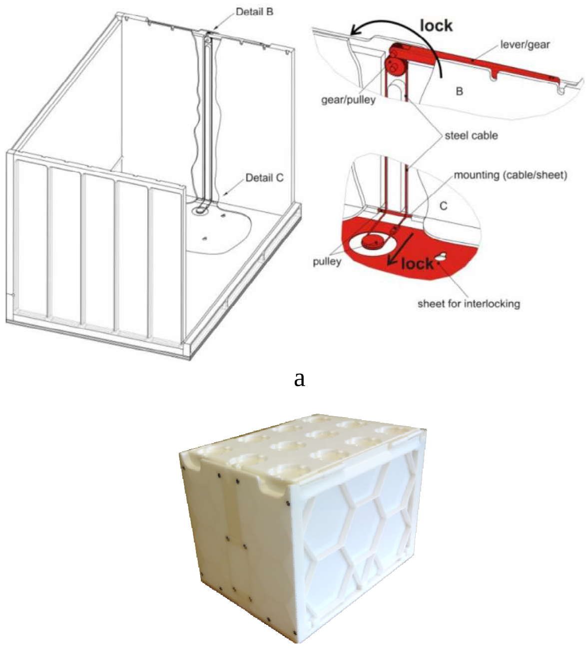

Fig. 9. M-Box: *a* – M-Box interlocking mechanism; *b* – 3D print prototype.

6. IDENTIFYING SUITABLE METHODS

Nowadays broadness of available knowledge in every scientific discipline challenges researchers as well as developing engineers to choose the appropriate knowledge. Within [15] an interactive model to choose suitable methods has been developed showing in three dimensions the overall usefulness of selected methods in different stages in engineering development. The dimensions are: horizontally – product development process, vertically (Fig. 5) – object size (Chap. 2.2), depth – main effect: varying or specializing. Therein (Fig. 10) coloured arrows depict acceleration in engineering processes graphically. Intelligent filters and 3D-viewing operations allow searching for suitable methods in different stages at different logistic objects (use [11] and the QR-Code in Fig. 10 for testing). This approach is now filled with the ten methods, identified effective for logistics engineering (Chap. 3 and Fig. 2) that are fully described in [15] and partly here (Chap. 4).

[5] Fast Moving Customer Goods: „are products that are sold quickly and at relatively low cost. Examples include non-durable goods such as soft drinks, toiletries, over-the-counter drugs, processed foods and many other consumables. In contrast, durable goods or major appliances such as kitchen appliances are generally replaced over a period of several years.” (Wikipedia 2016-04-11)

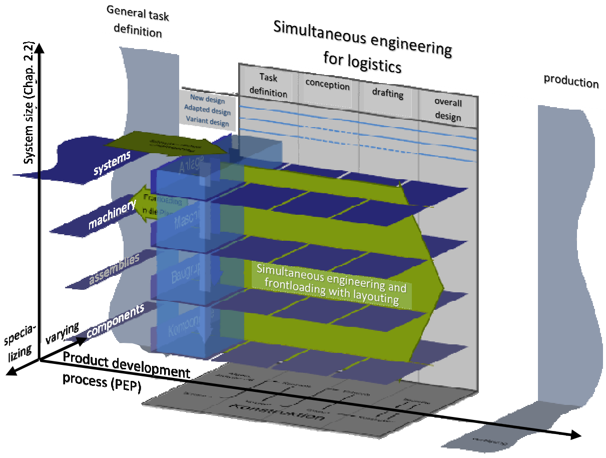

Fig. 10. Interactive 3D-model to depict and identify engineering methods – simultaneous (logistics) engineering [11].

It is up to further research to identify more suitable methods for depiction in the developed model to empower engineering development of material handling equipment and logistic products.

7. SUMMARY AND OUTLOOK

Methods allow engineers to perform their tasks more accurate and faster. Specific methods for logistics have been introduced and the identifying process (Fig. 2) allows to develop new ones under sometimes completely new assumptions.

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