Karlsruhe Institute of Technology

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IPEK
Institute of Product Engineering
at Karlsruhe Institute of Technology

A Methodology for Application-Specific Concept Definition of Battery Systems Using Pouch Cells Produced in Flexible Format

EVS Oslo – 35. Electric Vehicle Symposium

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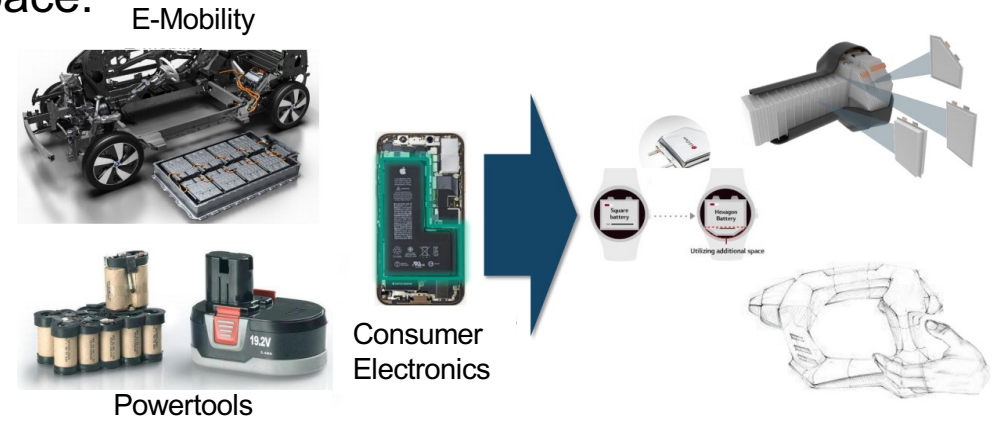
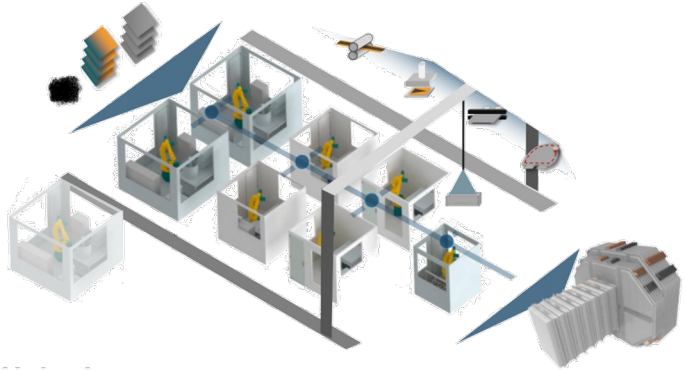
Motivation

- Battery systems currently consist of multiple **cells produced in standardized formats and high quantities.**
- Cell arrangement **possibilities are limited** by cell format resulting in unused installation space.
- Variable cell format offers **potential benefits for usage of available installation** space.



Research Objective



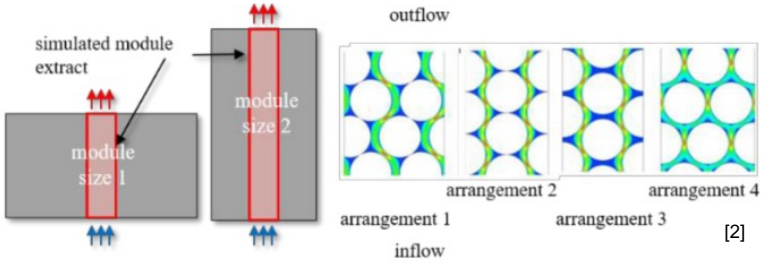
- Parallel development of product and production system[1]
  - Battery system **development based on flexibility in pouch cell production.**
  - **Optimization** of battery system properties by usage of potential of **new degrees of freedom .**

Methodology for development of battery systems using format flexible cells needed.

[1]J. Ruhland et al., “Development of a Parallel Product-Production Co-design for an Agile Battery Cell Production System,” in Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems, A.-L. Andersen et al., Eds., Cham: Springer International Publishing, 2022, pp. 96–104

State of Research

- **Choice of cell format and subsequent development** of modules and entire battery pack.
- Definition of cell amount and interconnection based on system requirements.
- Existing **approaches for arrangement optimization** regarding vehicle properties, cooling performance, structural properties.



[2]

²Eisele et al., “Evaluation of a validation process for a battery cooling system” presented at International Electric Vehicle Symposium, 2018

State of Research

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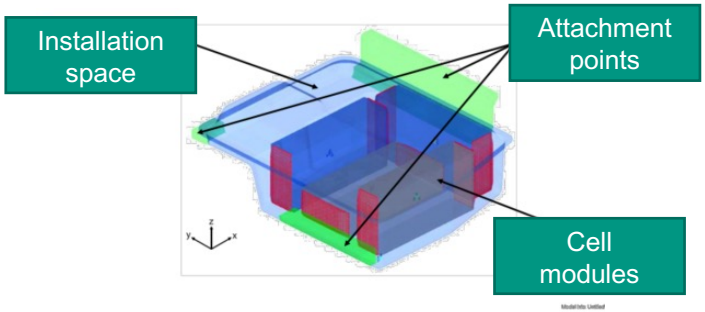
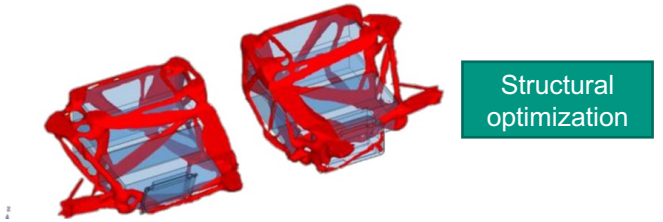


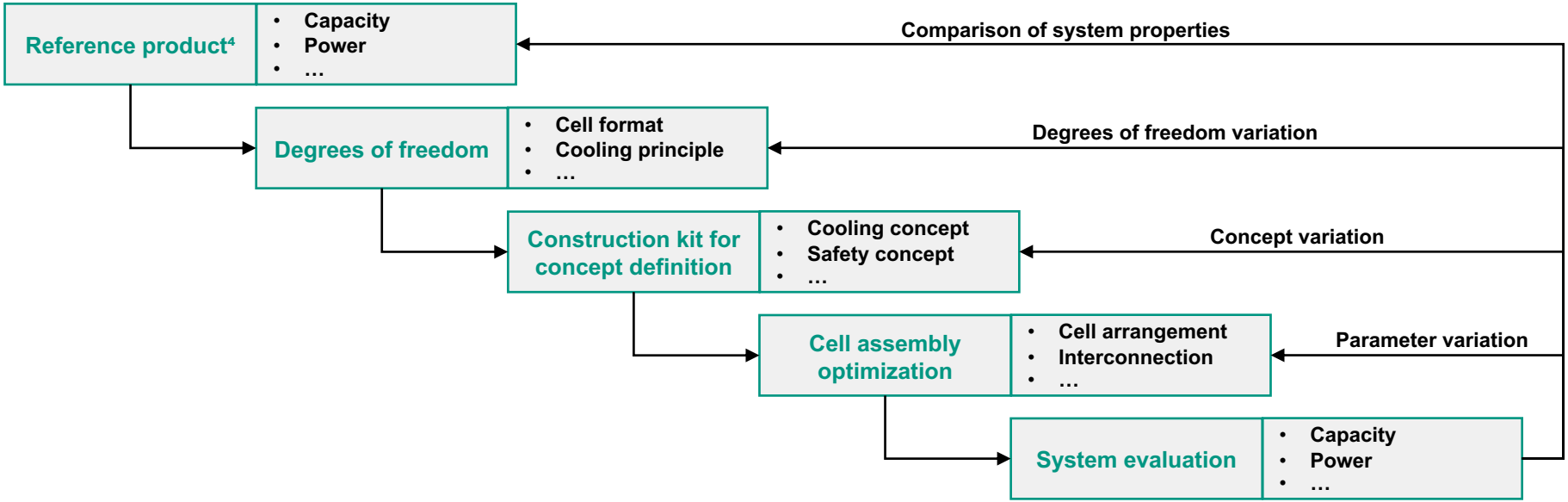


[3]

Currently no approaches investigating and using the potential of format-flexibly produced pouch cells under consideration of multi-domain dependencies.

[3]Wagner, "Methodengestützte Entwicklung eines elektrischen Energiespeichers zur Erschließung von Leichtbaupotenzialen als Beitrag zur Produktgenerationsentwicklung" in Albert Albers und Sven Matthiesen (Hg.): Forschungsberichte des IPEK - Institut für Produktentwicklung. ISSN: 1615-8113, Bd. 128. Karlsruhe, 2015

Research Approach



[4]A. Albers, S. Rapp, N. Heitger, F. Wattenberg, and N. Bursac, "Reference Products in PGE – Product Generation Engineering: Analyzing Challenges Based on the System Hierarchy," Procedia CIRP, vol. 70, pp. 469–474, 2018.

Research Approach
Challenges caused by format flexibility

- Increased **solution space** in development process due to **new degrees of freedom.**
- **Interactions** between mechanical, electrical and thermal domain **during optimization process.**
- Multiple **interdependencies between subsystems** of battery system.

Approach for **management of complexity and solution diversity** required

Research Approach
Definition of concepts and degrees of freedom

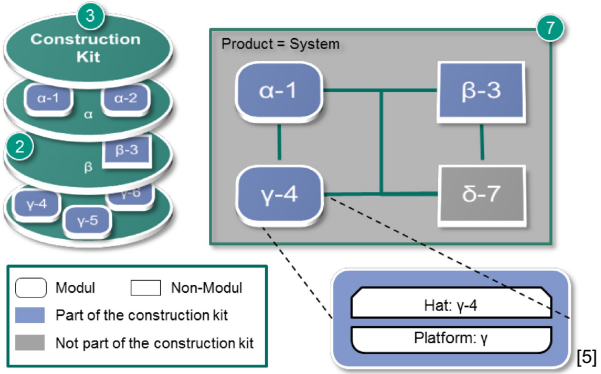
- Aim is to achieve a **defined set of concepts** with their individual subsystems and **according degrees of freedom.**

- Each **concept** can be **used for further optimization steps** and evaluated based on the resulting battery system characteristics.

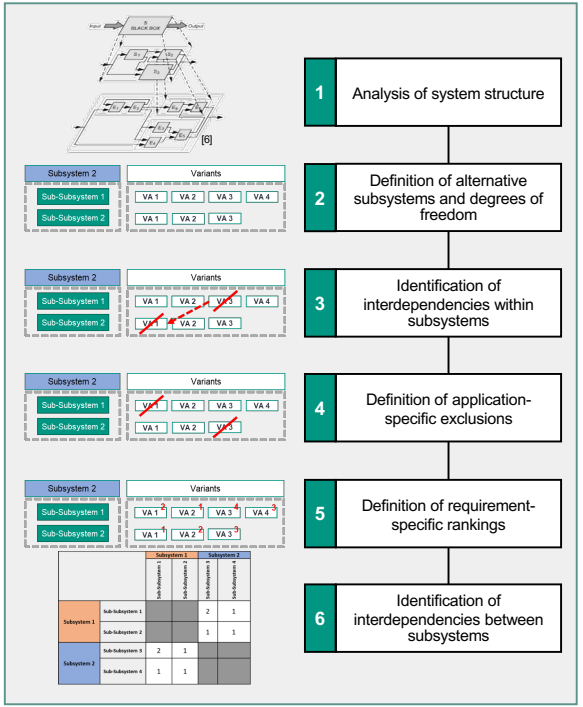
Concept definition	Subsystem	Degree of freedom	Values
Concept 1	Thermal barriers between modules	Length/width	[min – max] mm
		Thickness	t1, t2, t3 mm
	Liquid cooling plates within modules	Length/width	[min – max] mm
		Thickness	t1, t2, t3 mm
Concept 2	No Thermal barriers	-	-
		-	-
	Liquid cooling plate at installation space floor	-	-
		Thickness	t1, t2 mm

Construction kit development for concept definition

- A construction kit is the **set of all technical subsystems** that follow the associated construction kit rules, with the **aim of being able to configure technical systems** from these subsystems, each with a different set of functions.



[5]

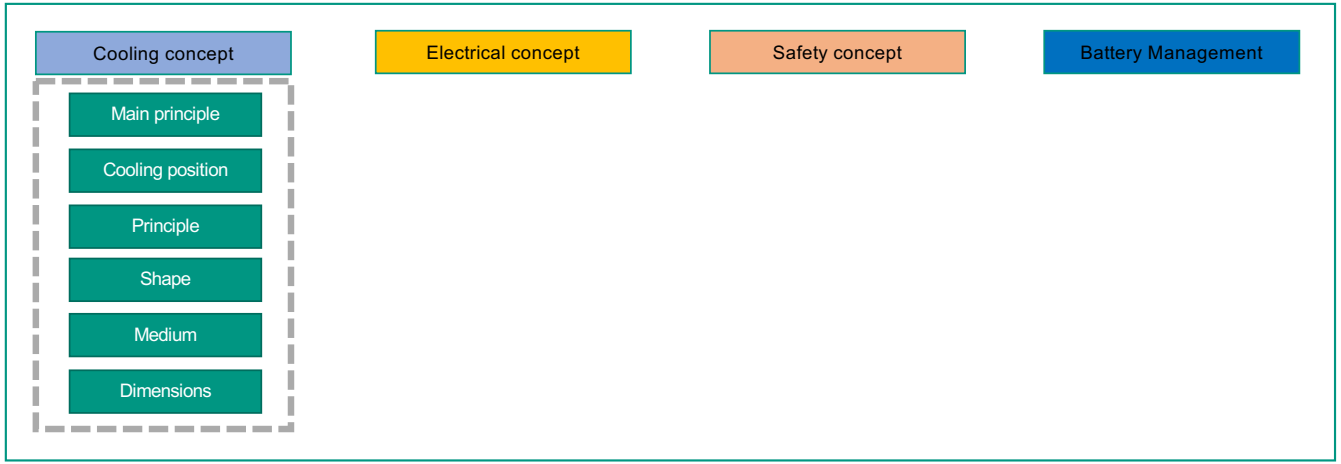


[5]N. Bursac, Model Based Systems Engineering zur Unterstützung der Baukastenentwicklung im Kontext der Frühen Phase der Produktgenerationsentwicklung. Dissertation. Karlsruhe: IPEK - Institut für Produktentwicklung am Karlsruher Institut für Technologie (KIT), 2016.

Construction kit development for concept definition
Definition of alternative subsystems and degrees of freedom

- The **construction kit structure** and its subsystems are based on a battery system structure.

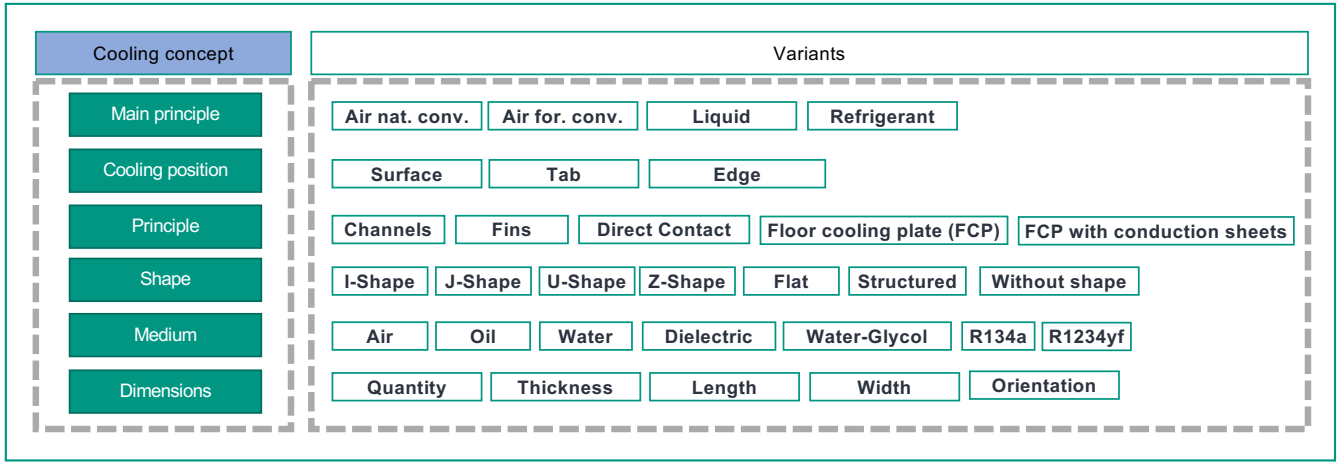
- For each of the main subsystems **potential variants** are identified based on **reference products and the defined degrees of freedom.**



Construction kit development for concept definition
Definition of alternative subsystems and degrees of freedom

- Based on subcategories in each subsystem **variants are defined** which are supposed to be part of the **construction kit subsystems.**

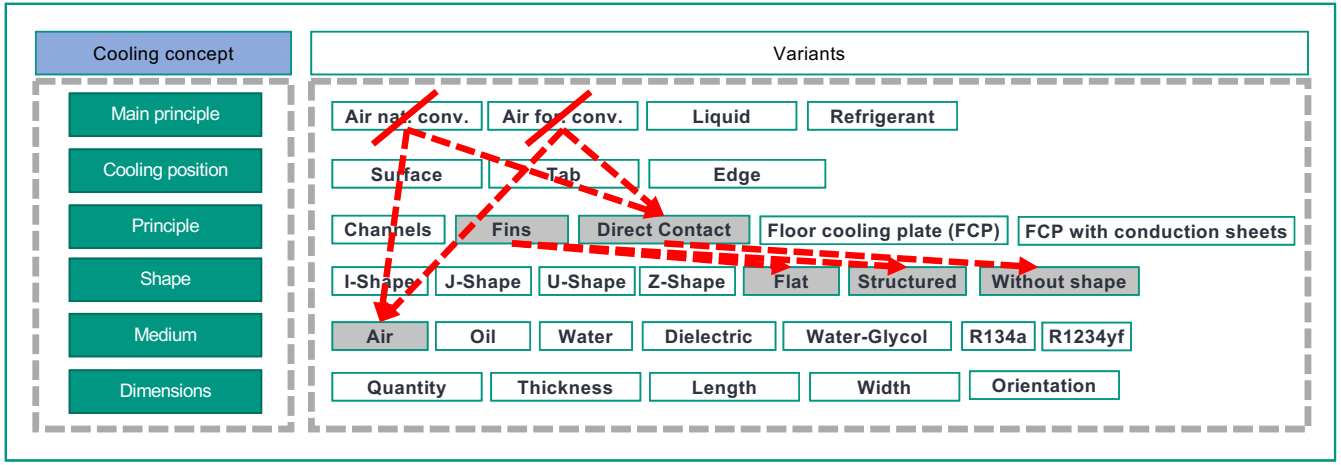
- All variants are **alternative principle solutions**, that can be selected **based on an specific application case.**



Construction kit development for concept definition
Identification of interdependencies within subsystems

- There are potential **interdependencies** within the subsystems that **might exclude some combinations** of principle solutions.

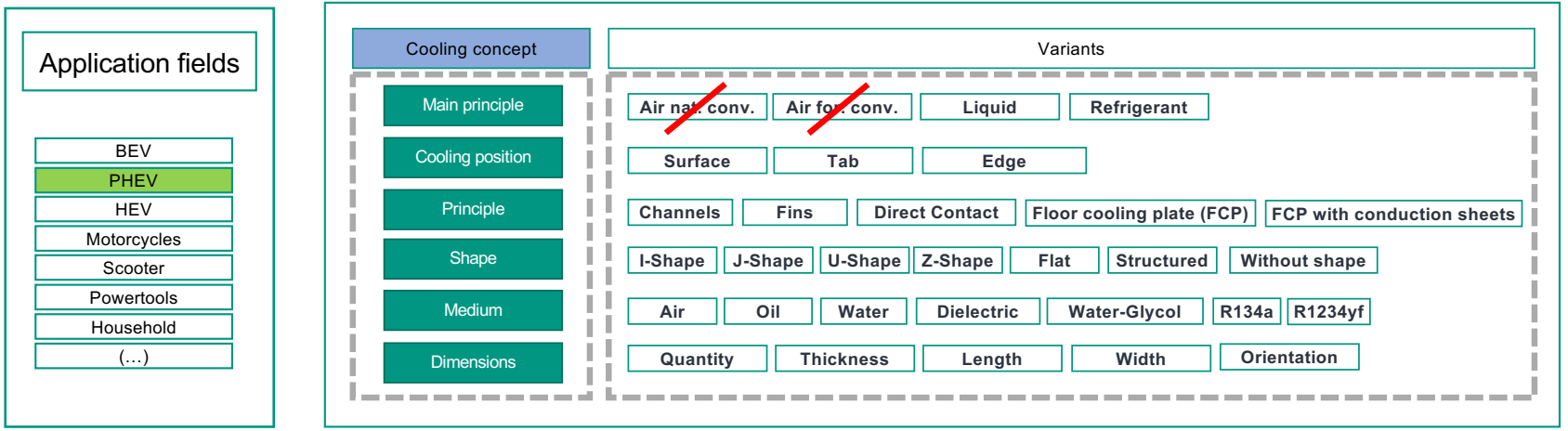
- Within the construction kit rules all **combinations of principle solutions that exclude each other** are defined.



Construction kit development for concept definition
Application based exclusion of variants

- For an **initial restriction of possible principle solutions** within the construction kit individual subsystems are excluded **based on a defined application scenario.**

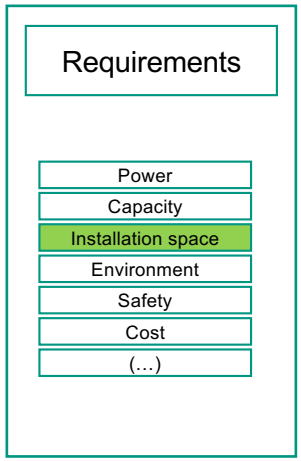
- Subsystems that are **not technically feasible** within an application case **are excluded** based on a set of rules of the construction kit.

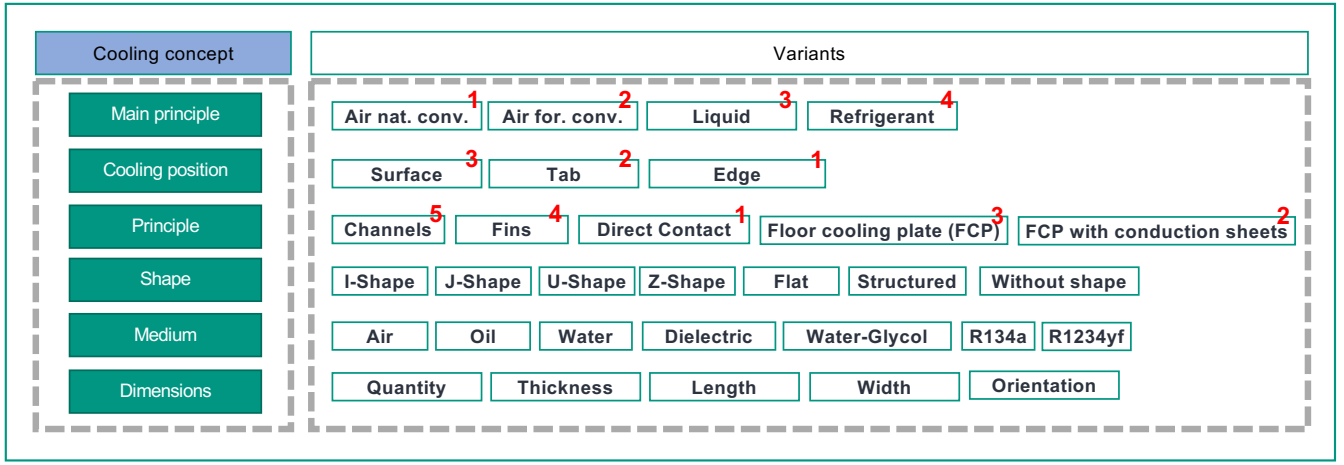


Construction kit development for concept definition
Requirement based selection of variants

- For **further selection of suitable principle solutions** within the construction kit individual subsystems are compared **based on a defined preferred requirement.**

- An evaluation and ranking of all variants is conducted based on preferred requirements to define an **order in the selection of subsystems** of the construction kit.





Construction kit development for concept definition

Identification of interdependencies between subsystems

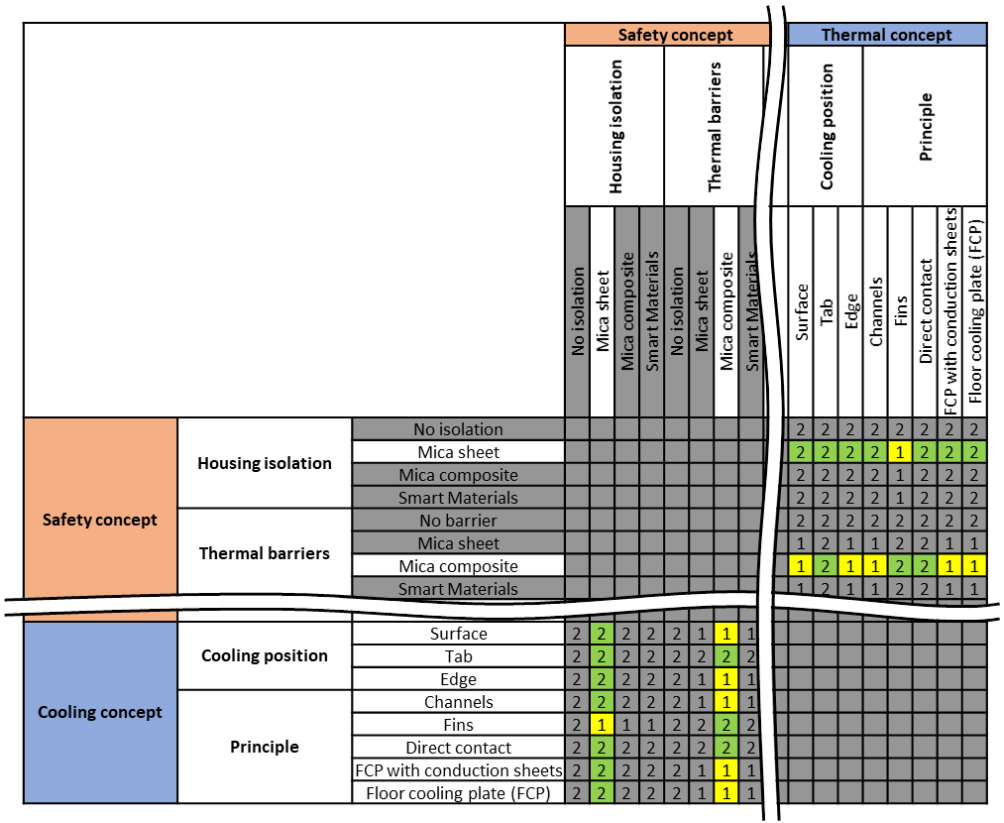
- **Dependencies between all variants of the subsystems** are evaluated on the basis of their **mutual compatibility.**
- Rating as:
  - Freely compatible (2)
  - Conditionally compatible (1)
  - Not compatible (0)
- Serves for an **exclusion of combinations** of subsystems and quick identification of **conditions** to be observed.

			Safety concept								Cooling concept							
			Housing isolation				Thermal barriers				Cooling position			Principle				
			No isolation	Mica sheet	Mica composite	Smart Materials	No isolation	Mica sheet	Mica composite	Smart Materials	Surface	Tab	Edge	Channels	Fins	Direct contact	FCP with conduction sheets	Floor cooling plate (FCP)
Safety concept	Housing isolation	No isolation									2	2	2	2	2	2	2	2
		Mica sheet									2	2	2	2	1	2	2	2
		Mica composite									2	2	2	2	1	2	2	2
		Smart Materials									2	2	2	2	1	2	2	2
	Thermal barriers	No isolation									2	2	2	2	2	2	2	2
		Mica sheet									1	2	1	1	2	2	1	1
		Mica composite									1	2	1	1	2	2	1	1
		Smart Materials									1	2	1	1	2	2	1	1
Cooling concept	Cooling position	Surface	2	2	2	2	2	1	1	1								
		Tab	2	2	2	2	2	2	2	2								
		Edge	2	2	2	2	2	1	1	1								
	Principle	Channels	2	2	2	2	2	1	1	1								
		Fins	2	1	1	1	2	2	2	2								
		Direct contact	2	2	2	2	2	2	2	2								
		FCP with conduction sheets	2	2	2	2	2	1	1	1								
		Floor cooling plate (FCP)	2	2	2	2	2	1	1	1								

Construction kit development for concept definition

Application of construction kit

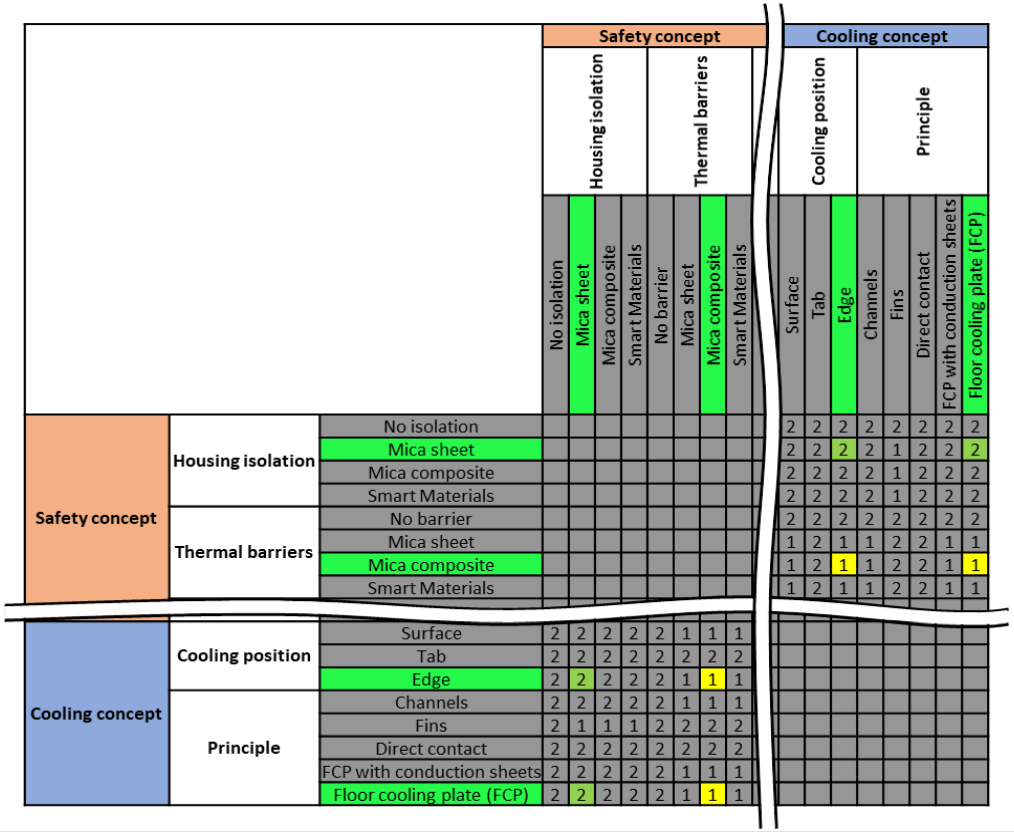
- By selecting a **target application**, previously **defined exclusions of individual subsystems** can be determined automatically.
- Combinations of these subsystems are thus **excluded as an possible output** of the construction kit.



Construction kit development for concept definition

Application of construction kit

- By selecting a preferred **requirement**, previously **defined suitable subsystems** can be determined automatically.
- **Combinations** of these subsystems are given as an output of the construction kit and serve as **basis for further design steps.**
- **Depending on selections** during usage of the construction kit **multiple possible combinations** of subsystems can be considered.



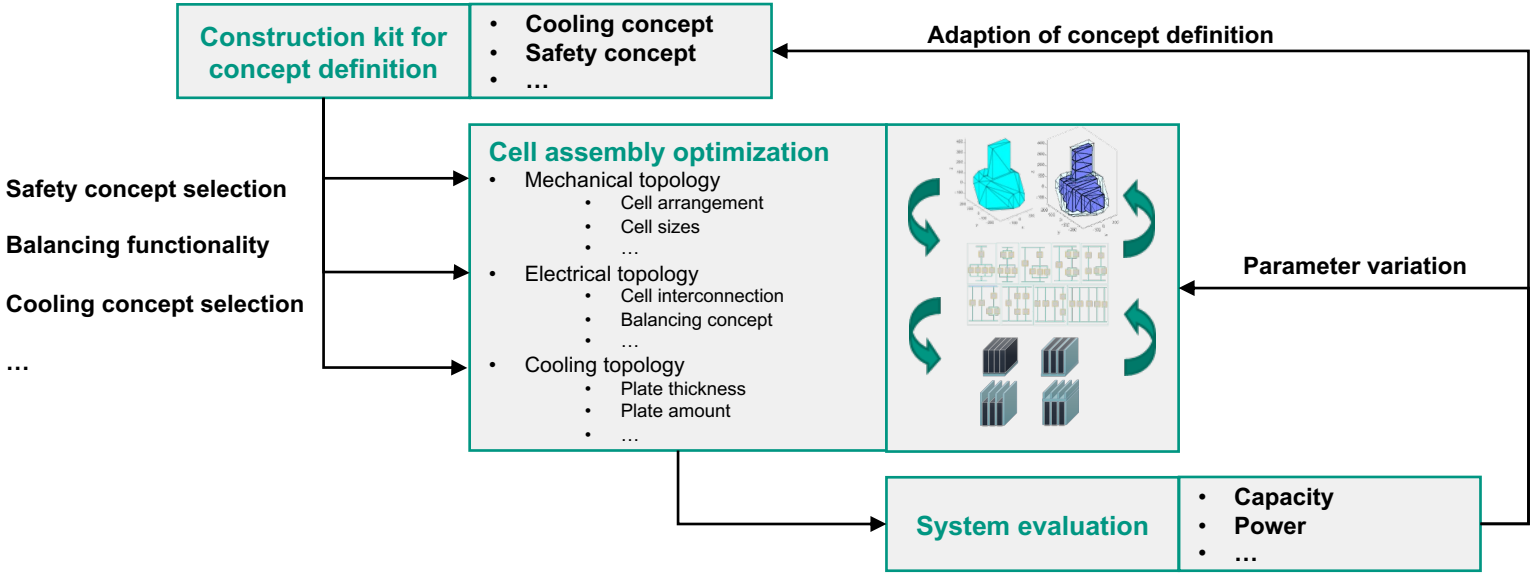
Construction kit development for concept definition
Output of construction kit

- Based on **input of the developer** a defined amount of possible **battery system concepts** is generated.

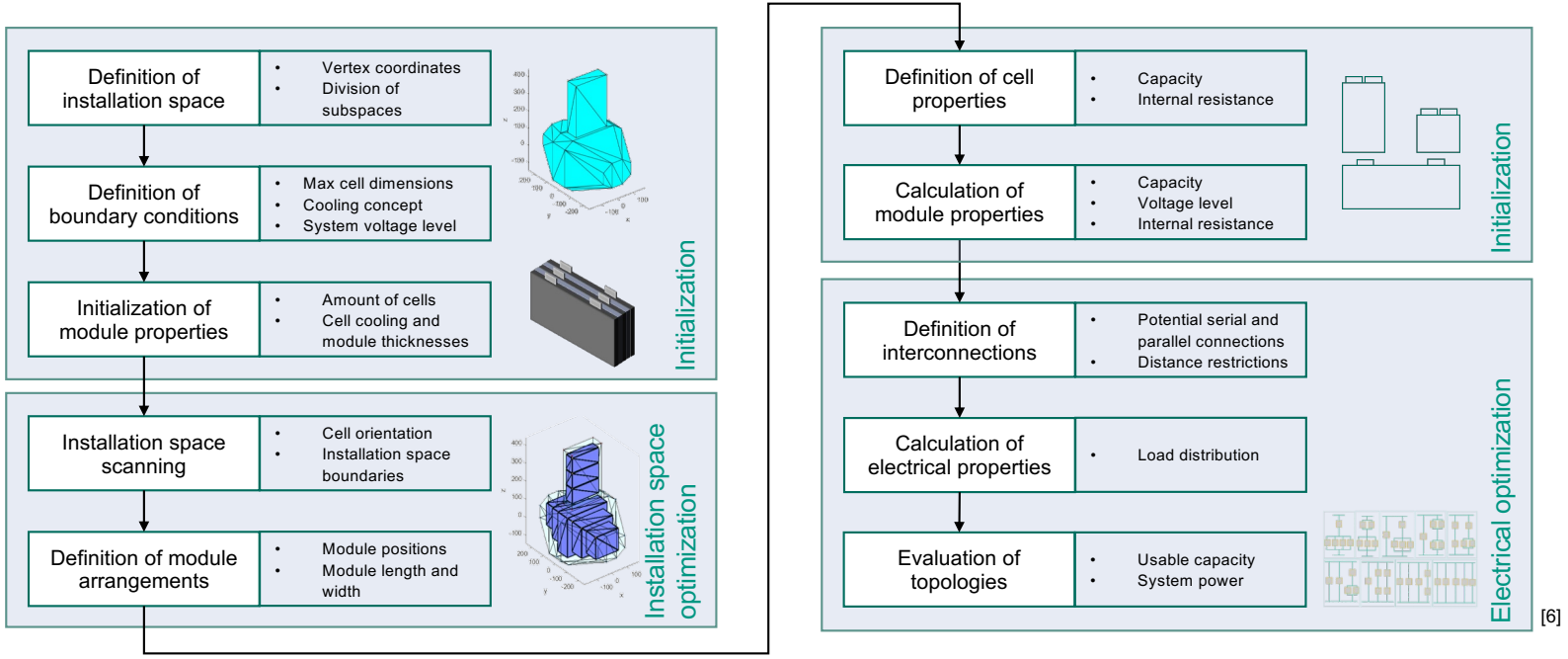
- Each concept consists of **individual subsystems and possible degrees of freedom** for further optimization steps.

Concept definition	Subsystem	Degree of freedom	Values
Concept 1	Thermal barriers between modules	Length/width	[min – max] mm
		Thickness	0.5, 1, 1.5 mm
	Liquid cooling plates within modules	Length/width	[50 – 350] mm
		Thickness	2, 2.5, 3 mm
Concept 2	No Thermal barriers	-	-
		-	-
	Liquid cooling plate at installation space floor	-	-
		Thickness	10, 15 mm

Research Approach
Further optimization steps based on concept definition



Methodology for Battery System Optimization



[6]P. Müller-Welt, K. Nowoseltschenko, C. Garot, K. Bause, and A. Albers, "Automated Optimization of a Cell Assembly Using Format-Flexibly Produced Pouch Cells," in 22. Internationales Stuttgarter Symposium, M. Bargende, H.-C. Reuss, and A. Wagner, Eds., Wiesbaden: Springer Fachmedien Wiesbaden, 2022, pp. 569–581.

Conclusion and Outlook
Conclusion

- The presented **methodology** offers a possibility **for the definition of battery system concepts for different application cases** using format flexible pouch cells in an early stage of product generation development.

- In combination with **further optimization steps** developers can use this method to **automatically generate and evaluate battery system configurations** with format flexible cells.

Conclusion and Outlook
Outlook

- **Combined consideration** of electrical, thermal, mechanical and safety aspects **in cell assembly optimization** for an overall **evaluation of benefits** of format flexible pouch cells.

- Extension of procedure to **other cell formats** such as triangular or trapezoidal cells, which would additionally enable even **better use of the installation space.**

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Thank you for your attention!

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