Life Cycle Design and Engineering Lab in the Open Hybrid LabFactory

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Abstract

Engineering processes for innovative and eco-efficient automotive components show a high degree of labour division. Domain-specific information needs to be exchanged between actors and serves as input for decision-making, e.g. information on part performance, weight, cost or environmental impact. In current engineering practice, this cross-domain communication tends to be streamlined up to the level of selected and simplified KPI that represent the progress of individual disciplines. This hinders a holistic improvement of products and processes. Research within the MultiMaK2 project emphasizes the importance of a joint knowledge building between engineering disciplines and aims at creating a cross-domain understanding of root causes for hotspots and goal conflicts. Therefore, the Life Cycle Design & Engineering Lab was established at the Open Hybrid LabFactory. It objectifies the methodological approach of visual analytics through domain spanning software toolchains, centralized data acquisition, analytics methods as well as a variety of visualization tools and hardware elements that serve the described goals.

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T. Vietor (ed.), *Life Cycle Design & Engineering of Lightweight Multi-Material Automotive Body Parts*, Zukunftstechnologien für den multifunktionalen Leichtbau,
https://doi.org/10.1007/978-3-662-65273-2_7

7.1 Automotive Life Cycle Engineering from the Open Hybrid Lab Factory's (OHLF) Perspective

The mitigation of negative environmental impacts of their products and processes is a major concern for the automotive industry. This encompasses the entire life cycle of vehicles, including raw materials, manufacturing, use and end-of-life stages. One example is the Volkswagen AG that announced to achieve a CO2-neutral mobility up to 2050 with an intermediate goal of reducing greenhouse gas emissions by 30% between 2015 and 2025 (Volkswagen AG n.d.). Against that background, new vehicle technologies need to be engineered, incorporating reduction targets for environmental impacts. Life cycle engineering (LCE) is a means to guide engineering processes with respect to overarching sustainability goals (Hauschild et al. 2017). Life Cycle Design & Engineering (LCDE) refers to a close link between engineering activities and their impact on the entire life cycle. At Open Hybrid LabFactory (OHLF), LCDE support has two starting points. First, engineering processes can be targeted that are in the direct focus of engineers at OHLF (foreground system). This includes the design and manufacturing of innovative body parts (see Fig. 7.1). Research in manufacturing could promote innovative designs, e.g. the combination of two materials on component level (technology push). In turn, adapted manufacturing processes could result from adapted design requirements (market pull). Second, design and manufacturing research at OHLF influences the entire vehicle life cycle and is, vice versa, influenced by the different life cycle stages. For instance, new component designs could pose challenges to recycling. In turn, requirements from those life cycle stages, e.g. expected vehicle lifetimes, can be translated to design requirements. LCDE therefore takes a cradle-to-grave life cycle perspective.

Within LCDE, life cycle assessment (LCA) serves as a foundational methodology to quantify environmental impacts of products and processes. However, the interface between the LCA method to product- or process-related engineering is cumbersome in practice. LCA requires expert knowledge to execute the method itself, including data

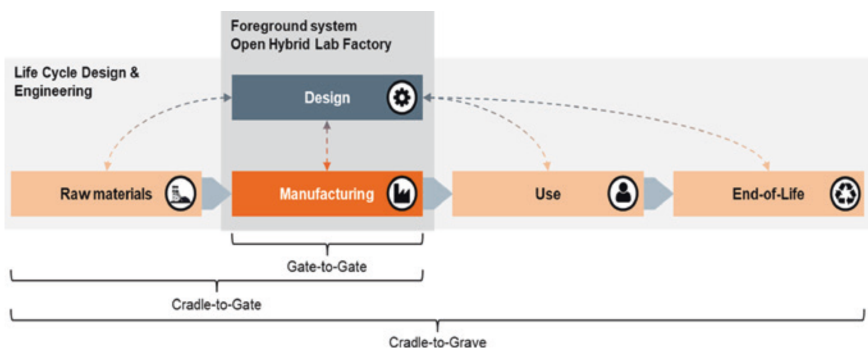


Fig. 7.1 System perspectives in Life Cycle Design & Engineering of automotive lightweight body parts at Open Hybrid LabFactory

acquisition and modelling as well as to interpret its results. This originates from complex interdependencies within the material and energy flows of a products' life cycle and multiple resulting impacts. At the same time, the scopes of engineering domains involved are rather. While domain-specific engineering decisions influence other life cycle stages, e.g. manufacturing cut-offs that affect waste streams, this cross-link is not emphasized in vehicle engineering.

Challenges for LCDE of vehicles increase with the shift to electric vehicles (EV) and new business models. For example, the effect of weight reduction on the use stage can be quantified with a low variability over different time horizons and geographic regions for ICEV. For EV, information on electric energy sources needs to be considered. However, electricity sources differ for every country and vary over time with increasing renewables in the supply (Egede 2017). Thus, if vehicle body parts are designed for different markets and one or more vehicle generations, no unambiguous statement on potential use stage benefits can be provided to the body part engineering teams. Therefore, decisions on favourable concepts are hampered.

The engineering of manufacturing technologies at OHLF ranges from laboratory to semi-industrial and industrial scales. In the sense of LCDE, this enables to design key process characteristics as well as to assess associated data, e.g. on preferable process windows, resulting cost, quality, time and associated environmental impacts. LCDE at OHLF enables to explore potential trade-offs and direct development, e.g. towards efficiency gains.

7.2 Background

Several research demands have been identified in relation to enhancing the application of LCA-based LCDE within previous research (Kaluza et al. 2018, 2019). This encompasses the identification of hotspots across different life cycle stages, impact categories, or sub-systems of a product, the comparison of two or more products or technologies, the identification of trade-offs, the assessment of technological, geographic or temporal variability as well as the identification of engineering levers to influence environmental and cost impacts. Table 7.1 presents a reworked summary of research demands based on previously published articles.

7.3 Understanding LCE through the Eyes of VA

When bringing together the challenges of LCDE with the goals of visual analytics (VA), potential synergies emerge. VA can be described as "the science of analytical reasoning facilitated by interactive visual interfaces" (Thomas and Cook 2005). VA is a human-centred process that enables the forming and testing of hypotheses and intends to reduce complex cognitive (engineering) work to process large data sets towards an

Table 7.1 Research demands for improving the application of LCA in engineering contexts, based on (Kaluza et al. 2018, 2019)

Challenge	Description
Strengthen prospective application of LCA	• LCA relies on quantified inventory data that is typically assessed for past time periods (retrospective character) • Additional methods and tools need to be introduced to allow prediction regarding specific life cycle stages or parameters, e.g. simulation- or data-based forecasting, scenario analysis
Increase accessibility of complex LCA models	• LCDE tools that streamlined LCA emerged in the past, e.g. linearized calculation methods, acceptance of data gaps, simplified and/ or aggregated KPI (Rossi et al. 2016) • Inherent complexity of LCA results is neglected in simplified tools and hinders to identify complex mitigation strategies • Advanced computational LCA models enable to overcome this challenge, as e.g. shown by Cerdas et al. (2018)
Integrate different engineering scopes	• Certain levers to decrease environmental impacts are not in the engineering scope of the target audience, e.g. parallel engineering activities targeting • Other vehicle sub-systems and/ or • Upstream or downstream life cycle stages
Leverage primary (real-time) data	• Hard- and software for collecting primary product and process data is improving and can be leveraged for LCA • Acquisition, storage and analysis of life cycle related data • Processing and real-time feedback (Cerdas et al. 2017) • Goal: improvement and tailoring of inventory databases through generation of specific life cycle inventory data, e.g • Live mapping of energy and resource flows from manufacturing stage to the environmental impact (Cerdas et al. 2017) • Leveraging of use stage data for different user behaviours, e.g. driving patterns or geographic conditions (Li et al. 2016)
Provide tailored visualizations	• Current approaches for interpreting LCA studies tend to fail the demands of engineers and decision-makers (Laurin et al. 2016) • Potential reasons: overcomplexity, oversimplification, missing standards in results presentation, individual preferences, different target audiences, weak recommendation for action, e.g. feedback to adapt design parameters

informed decision-making (Kohlhammer et al. 2011). VA methods empower users to handle massive, dynamically changing data sets, detect expected and especially unexpected events, e.g. anomalies, changes, patterns and relationships, in order to gain new knowledge (Cook et al. 2007). Keim et al. structured constituting elements and processes of VA by describing the interplay of data acquisition, models, visualizations and knowledge building (Keim et al. 2009). The process has been adapted to the LCA methodology (Fig. 7.2) (Kaluza et al. 2018). In parallel to the key activities of VA, the analogies to an LCA-based LCE support are elaborated. These encompass inventory data acquisition, modelling, visualization and interpretation as well as the derivation of knowledge, as described in the previous section. A focus is set on challenges in performing and connecting the required activities with state-of-the-art methods and tools.

Data Inventory data builds the basis for any LCA study. Typically, studies combine primary and secondary data sources according to the goal and scope. Primary data can result from dedicated assessment campaigns or business information systems; secondary data sources mainly encompass commercially or publicly available inventory datasets and research studies. Pre-processing is a main task at the data stage. Primary data treatment requires activities like data cleansing, normalization, transformation as well as feature extraction. With respect to secondary inventory data, the challenge lies in the selection of appropriate datasets, e.g. with respect to key characteristics, system boundaries or spatial contexts.

Modelling LCA studies require a modelling of energy and resource flows, depletion of resources and emissions associated to a product or process of interest. LCA modelling relies on the integration of different domains and respective engineering models to map different life cycle stages. Dedicated software tools assist the inventory modelling. Overall inventory flows serve as an input for impact assessment that allows the derivation of environmental impacts, e.g. greenhouse gas emissions (GHG) measured in CO2-eq. Other functionalities are the variation of models through sensitivity analyses

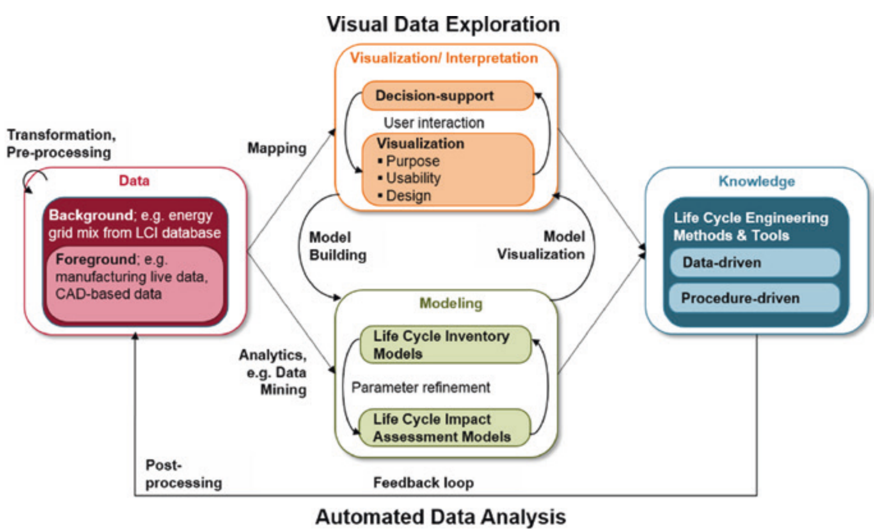


Fig. 7.2 Framework for understanding life cycle engineering through the eyes of visual analytics, previously published in (Kaluza et al. 2018), adapted from (Keim et al. 2008)

or the structured analyses of uncertainties. While traditional LCA tools enable a rather static modelling, dynamic system behaviours, e.g. in manufacturing, might be determined by specific engineering tools. This encompasses simulation-based as well as data-based methods.

Visualization/ Interpretation A major motivation of LCE is to translate LCA insights to engineering measures and decisions, ranging from ad hoc feedback within the engineering process up to decisions on a management or policy level. Life cycle impact assessment forms the basis for the interpretation of LCA results. In line with the listed insights of LCA studies as listed in Chap. 6, different visualizations can be chosen. Dedicated LCA tools provide visualizations that enable one or more of the described functionalities. However, on one hand this covers a high level of detail where high efforts are required to identify the relevant information for a given task. On the other hand, aggregated visualizations are incorporated at the level of non-experts. While allowing a quick interpretation, information on system dependencies is lost. Another stream is the representation of inventories, e.g. Sankey diagrams. In general, static visualizations dominate current LCA tools.

Knowledge A general distinction can be drawn between explicit and tacit knowledge derived from LCA studies. The management of explicit knowledge is very common in industrial and policy practice, e.g. by applying fixed rules. However, identifying and imparting tacit knowledge is a key challenge for every organization (Haldin-Herrgard 2000). LCA results typically allow case-dependent statements on the environmental impacts of product systems: "If product A is applied under the given circumstances, then the life cycle impact will be lower than for product B". This complexity leads to a translation of insights from LCA studies into domain- and application-specific methods and tools. The cumulated insights accelerate the LCE process for those specific domains. As well, continuous knowledge generation enables to enhance modelling and decision support.

7.4 The Life Cycle Design Engineering Lab (LCDEL)

The Life Cycle Design & Engineering Lab (LCDEL) has been initially set up with hard- and software to objectify the presented VA workflow and bundle research on life cycle-oriented automotive product and process engineering as well as digitalization research at OHLF. LCDEL is located at the shop floor level with a direct interface to manufacturing operations and analytics.

Three strategies are inherently linked to LCDEL's set-up and operation. First, enabling a life cycle perspective is seen as one of the key potentials as well as a necessity in engineering of future vehicle technologies. Research at OHLF focuses on gate-to-gate processes within the automotive life cycle, bringing forward innovative designs, materials and manufacturing processes. By providing insights from raw materials extraction, use stage and end-of-life, OHLF's engineering activities could be guided with those stages in mind. Second, a constant transfer of research findings to industrial practice is promoted through LCDEL. It provides state-of-the-art methods, hardware and software tools, ranging from commercialized solutions to scientific prototypes. LCDEL enables to initialize research activities in collaborative projects between academia and industry. The third strategy covers the exploration of engineering tools and technologies. Engineering research is simultaneously driven by technological innovations (pull) and brings forward innovative technologies at the same time (push). Therefore, a broad variety of hardware and software is provided and constantly updated.

Based on the presented strategies, three major application scenarios have been derived for LCDEL (see Table 7.2). Those cover the engineering of innovative automotive parts and their manufacturing technologies, the functionality as a Nerve Centre for OHLF's manufacturing engineering activities as well as a location assisting the progress of engineering meetings and review meetings on different decision levels.

The application scenarios emphasize LCDEL's character as a platform for performing research activities across scientific domains as well as to communicate research progress and key results between researchers and to decision-makers in industrial or policy contexts. The operation of LCDEL is strongly linked to the project portfolio of OHLF that covers short- and long-term projects solving current industrial demands (high TRL), collaborative industrial and academic research (medium TRL) as well as well as fundamental research activities (low TRL).

Table 7.2 Application scenarios of LCDEL at Open Hybrid LabFactory

Application scenario	Sub-elements
1. **Integrated engineering** of innovative automotive body parts and manufacturing technologies	• Conceptual design of innovative body parts • Planning of manufacturing process chains for multi-material components • Life cycle and cost assessment • Integration of engineering activities
2. **Nerve Centre** for OHLF manufacturing engineering	• Monitoring of live data • Process level: control parameters, process data, energy and material flows, part quality • Technical building services (abatement, climate control): control parameters, process data, energy demands • Process control and improvement based on live data (quality, time, cost, environmental impact) • Data- and simulation-based insights • Automated process control (CPPS)
3. **Engineering meetings and reviews**	• Creative working environment • Flexible configuration for different group sizes • Suitable for engineering activities as well as high level decision-making • Leveraging the potential of visualization

Table 7.3 Constituting elements of the Life Cycle Design & Engineering Lab (LCDEL)

VA	Elements	Implementation
D	**Energy data acquisition and storage (OHLF)**	- Real-time and historic energy data for individual manufacturing processes and technical building services - Siemens PAC, SENTRON Powermanager - OPC-DA Client/Server - WinCC 15.1 professional
	Process data acquisition and storage	- Real-time and historic process data of manufacturing processes, PLC access - Modbus, OPC UA - WinCC 15.1 professional
	Life cycle inventory (Secondary data)	- Energy & material flows for processes out of scope of OHLF - thinkstep GaBi SP38 (Professional + Extension DB) - Ecoinvent 3.6 - Further inventory data collection (state of research, primary)
M	**Data & simulation-based modelling**	- OHLF (gate-to-gate): - Goals: process understanding, prediction, efficiency improvements, scale-up behaviour, process planning, assessment of energy and resource flows - Outside OHLF (cradle-to-gate, gate-to-grave): - Goals: representation of upstream and downstream processes, e.g. raw materials sourcing, use scenarios, … - Data-based modeling: Python, Node RED, KNIME, … - Simulation-based modeling: Matlab Simulink, Anylogic, Plant Simulation,...
	Life cycle assessment	- Environmental impact assessment based on energy and material flows - Integration of sub-models from data- and simulation-based modelling - Tools: Umberto LCA+, Open LCA, thinkstep GaBi, Brightway2
V/I		- 4*4 Screen multi-input video wall, Barco Clickshare - Microsoft Surface Hub Interactive Display - Mixed Reality Head-Mounted device Microsoft HoloLens - Virtual Reality Head-Mounted devices, e.g. HTC Vive - Tools: Business Intelligence, Data Visualization, Interactive Visualization,…
	General lab equipment	- Flexible tables, chairs, high desks, variable partition walls to suit different workshop and review situations - Writable wall panels (6*2 meters)

The current hardware implementation of LCDEL is listed within Table 7.3. It can be classified according to the VA levels and serves the different application scenarios. Core hardware elements include live data acquisition of process, energy and material data, servers, visualization hardware as well as general lab equipment. The hardware is complemented by a range of software applications. Fig. 7.3 presents impressions of LCDEL at OHLF.

Fig. 7.3 Impressions of the LCDEL at Open Hybrid Lab Factory

7.5 Use Case 1—Life Cycle Engineering in Conceptual Design

The first use case targets the life cycle engineering support of the conceptual design stage for lightweight vehicle bodies (Chap. 2). Therefore, the target audience comprises design engineers as well as project engineers. Both groups of interest have been identified within an initial analysis of typical decision situations in engineering of automotive structures as part of the project MultiMaK2 (Kaluza et al. 2016).

The upper part of Fig. 7.4 (A, B1–3, C) illustrates the engineering context. Design engineering proposes a set of concept alternatives based on given requirements (B1) including different geometries and material combinations (Kaluza et al. 2016). Three geometries of a component cross section (full shape, U-shape, reinforced U-shape) are compared that could be manufactured with different materials and manufacturing processes. Technical parameters like wall thickness can be influenced by engineering design. Mechanical performance of conceptual designs is evaluated, and several alternatives are handed over to an LCA expert (B2) that evaluates scenarios for life cycle environmental performance. Decision-makers, e.g. project managers, need to interpret reports from the domain experts with respect to specific assumptions and scenarios (B3). The lower part of Fig. 7.4 represents an improved engineering process by applying principles of Visual Analytics, in this case realized by implementing a system that integrates LCA modelling and MR visualization (BN1 – BN3). Following this approach, potential trade-offs between design parameters, associated environmental impacts and background scenarios can be determined within ad hoc feedback loops (Kaluza et al. 2019).

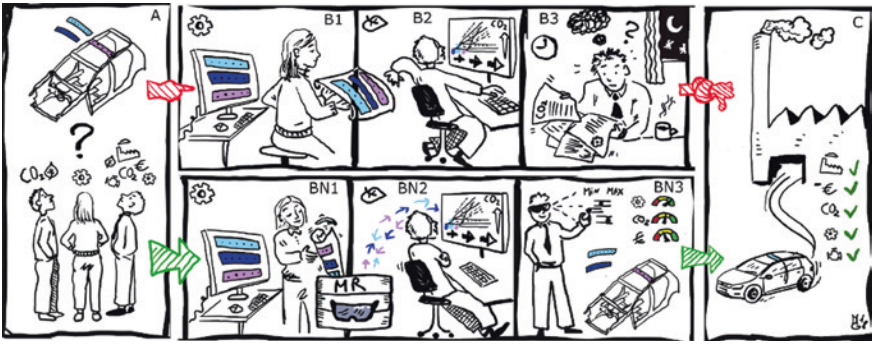


Fig. 7.4 Conventional workflow in automotive LCE and concurrent approach based on MR and VA, reproduced from (Kaluza et al. 2019)

Fig. 7.5 illustrates the described engineering situations applying the VA framework. The concept of LCDEL's workflow to support conceptual design will be examined in more detail in the following.

Knowledge layer There are two main goals of enhanced LCDE support in engineering design of automotive body parts through VA.

- Decision-making: Concept alternatives with low environmental impacts should be identified at early stages of conceptual design. Thereby, variability of different fore- and background systems should be considered. Only a small number of conceptual designs should be identified that will be further detailed towards series development.
- Exploration: This task's goal is to enable knowledge gains between the disciplines' engineering processes and thus increase acceptance and effectiveness of suggested LCDE workflows. Therefore, the design space of life cycle environmental impacts and conceptual designs is jointly explored incorporating different materials. For example, what-if scenarios can be performed that show the effect of a parameter variation, e.g. manufacturing yield or process efficiency, to overall life cycle environmental impacts. Other examples would be the analysis of different LCA modelling paradigms or the comparison of different secondary data sources. Exploration incorporates an active engagement of engineers and/ or decision-makers.

Data layer The data layer combines different fore- and background data of a component's life cycle. Primary foreground data is acquired from OHLF manufacturing processes, as described within the following use case (Sect. 7.6). Secondary inventory data is integrated from professional LCA databases, i.e. Ecoinvent or thinkstep GaBi. Another source of secondary data is published information from the state of research. As a large number of innovative manufacturing processes are compared, data availability with respect to expected energy and material demands is typically low. This is especially true

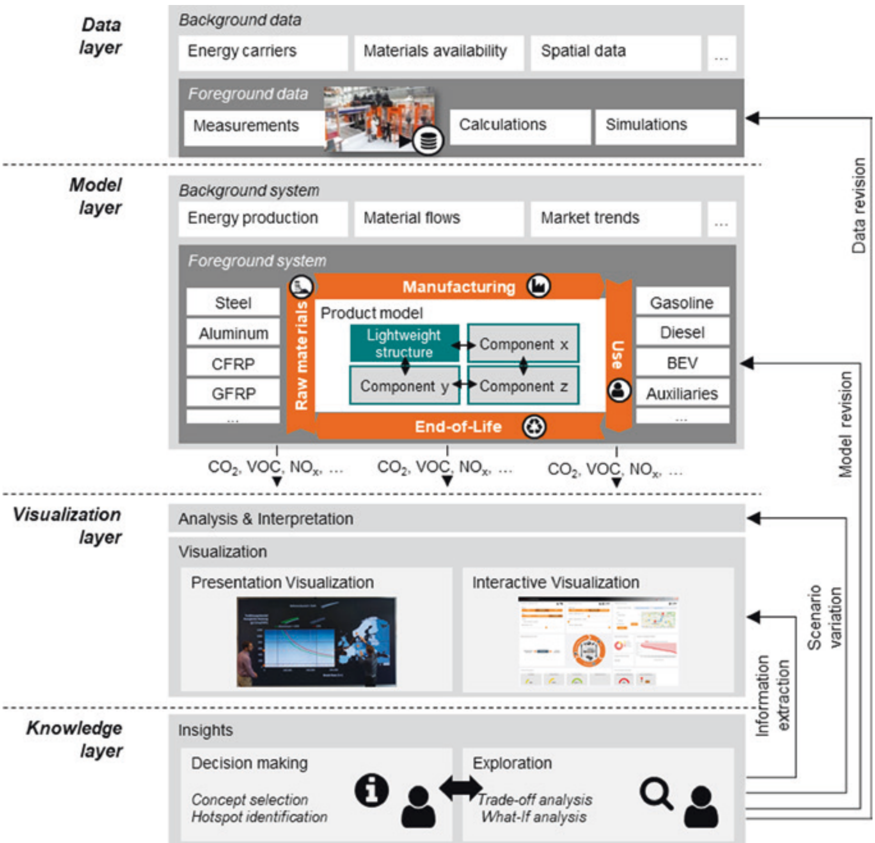


Fig. 7.5 Application of the Visual Analytics Framework for Life Cycle Engineering in Conceptual Development

for determining product-specific data. While quality-assured secondary data might not be available for all conceptual designs, ongoing research projects might provide indications on this data based on lab-scale or semi-industrial processes.

Model layer The model layer integrates all life cycle stages and associated energy and material flows into a life cycle inventory model. The core model is typically realized within a dedicated LCA software, i.e. Umberto LCA+, thinkstep GaBi, open LCA or Brightway2. Within those tools, primary and secondary data can be integrated into a joint inventory model. However, as described from the data layer, sub-models might be required to derive inventory data for different sub-systems within the life cycle. In some cases, this refers to calculations, e.g. the linearized fuel reduction value, in other cases simulation- or data-based approaches need to be applied to estimate energy and material flows (Chap. 5 and 6).

The model layer as well requires to consider variabilities of different sub-systems. In the course of developing innovative body parts, variabilities could occur at different points on the vehicle life cycle. For example, calculations on component weights of new designs in first iterations of conceptual design need to be refined and verified during detailed design stages and the integration into a specific vehicle. In this course, adaptions could occur that influence weight or material environmental impacts, e.g. additional reinforcements, cut-outs, adapted fibre grades and so on.

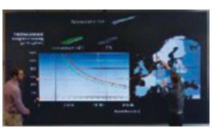
Visualization layer Table 7.4 lists a range of visualizations developed to assist conceptual design of automotive body parts as knowledge insights. Visualizations can be generally classified into presentation visualization and interactive visualizations as well as intermediate versions. Presentation visualization intends to serve as results communication to a lager target audience without allowing user interaction. In contrast, interactive visualization re-renders on user input. Thus, it promotes user-led discovery of insights. Interactive visualization is typically applied by one user or smaller groups of users, e.g. within engineering meetings. Other distinctions can be made in terms of embodiment of visualizations. For example, mixed reality applications combine real and virtual content, are interactive in real time and are registered in three dimensions (Kaluza et al. 2019). For example, this could be leveraged if 3D models or body parts are available and need to be contextualized with other, physically present vehicle parts of a vehicle. LCDEL aims at exploring different visualization methods and adapts them to the needs of respective users on a project basis (Figs. 7.6, 7.7 und 7.8).

7.6 Use Case 2 – Open Hybrid LabFactory Nerve Centre

Complex value chains and high energy and resource demands characterize the production of automotive lightweight parts. The target of designing eco-efficient production processes at OHLF calls for transparency towards efficient process parameters, the current process behaviour, product quality as well as associated energy and resource demands. As introduced within Chap. 4, industrial data acquisition and analysis is a vital approach towards achieving a comprehensive transparency. This should help to understand and influence interactions between process parameters and structural parameters as well as between structural parameters and component properties.

To this end, a Nerve Centre approach is pursued, which is based on the framework of cyber physical production systems. The Nerve Centre represents the central data hub and analysis platform. Collected data is modelled using machine learning and simulation methods and transformed into novel visualizations for discussion of analysis results and decision support. The visualizations are made available via various devices, such as augmented reality devices or a large 184 inch video wall. The latter is particularly suitable for the depiction of a complex manufacturing monitoring system, which covers the production in the technical centre both on process and factory level (see Fig. 7.9).

Table 7.4 Visualization portfolio for application in conceptual design

Application	Type	Realization	Knowledge Insights
Joint Concept Engineering	Presentation visualization	Multi-input video wall Display of intermediate engineering results	Elaboration of the design space and boundary conditions Early stage evaluation of conceputla designs
Joint Concept Engineering 	Interactive visualization	Mixed reality device (Microsoft HoloLens) 3D models of conceptual designs Structured LCA results	Elaboration of the design space and boundary conditions Early stage evaluation
What-If Analysis 	Interactive visualization	Interactive display Web-based or Business Intelligence (Microsoft PowerBI) Integration of external data, e.g. energy, traffic Interface to parameterised LCI model	Contextualization of foreground and background data Identification of trade-offs Narrowing down of design parameters
Concept Selection 	Presentation visualization	Single-input video wall Focused selection of few concepts with respect to key parameters Dedicated data visualization libraries, e.g. Seaborn, Vega (Python) + Manual editing	Narrowed down concept comparison Informed decision-making

The Nerve Centre enables a transparent and holistic view on OHLF production. In addition, valuable information can be obtained for further analyses, such as the environmental assessment of hybrid parts. The concept of the Nerve Centre's monitoring system is outlined in the following. As shown in Fig. 7.10, the toolchain of the monitoring system is described by means of the visual analytics framework.

Knowledge Layer As outlined above, the monitoring system intends to support the user in the assimilation of knowledge on the process chain for the manufacturing of hybrid

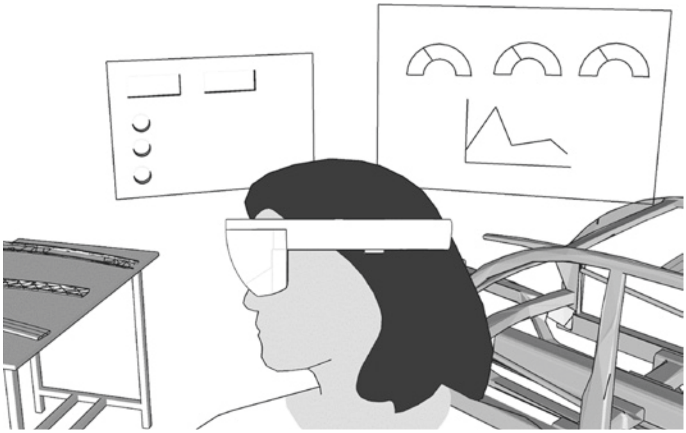


Fig. 7.6 Joint Concept Engineering—Interactive visualization—Microsoft HoloLens

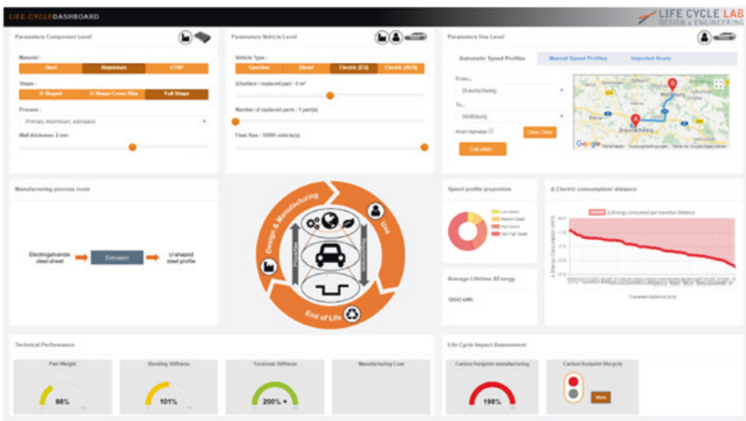


Fig. 7.7 What-If Analysis—Interactive display

parts through (interactive) visualization methods. The concept of the monitoring system pursues several objectives:

- Decision-making: identification of hotspots at process and factory level (e.g. technical building services) or anomaly detection in process or energy parameters in contrast to a standard behaviour.
- Deeper process analysis: process and data understanding for supplementary deeper cause–effect analysis through the application of machine learning algorithms or the

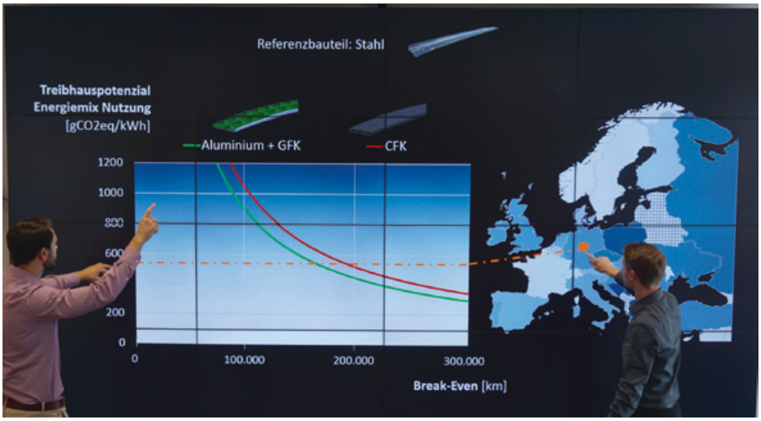


Fig. 7.8 Concept selection—Presentation visualization

Fig. 7.9 Monitoring system at the Nerve Centre of the Open Hybrid LabFactory

usage of the acquired data for parameterization of simulation models (e.g. process and factory simulation).

- Staff development: reduction of entry barrier for students, employees and externals towards the production technologies and intelligent production data analysis.

Data Layer

In order to meet these objectives, the process and energy data of the technical centre is acquired, modelled and transferred into tailored, interactive visualizations in accordance to the visual analytics process. The data layer of the Nerve Centre is composed

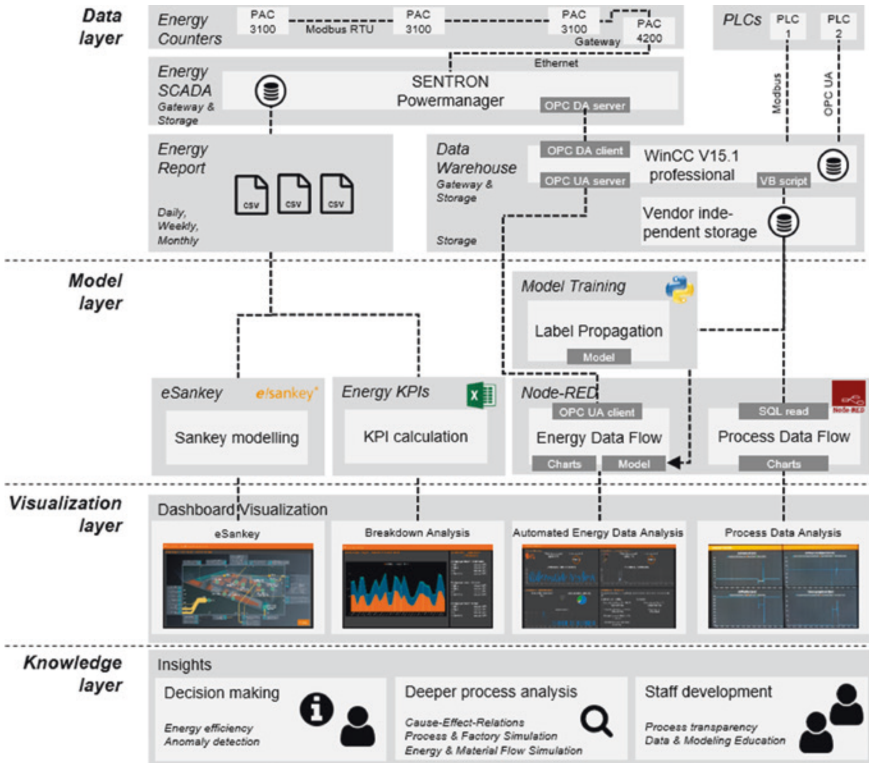


Fig. 7.10 Application of the Visual Analytics framework for process monitoring

of two different data sources. Firstly, energy metering is done through 73 SENTRON PAC energy meters (PAC 3100, 3200 or 4200). The PAC 4200 m serves as an Ethernet-capable gateway to the SCADA system for energy data, which is implemented in terms of the SENTRON powermanager.[1] The software offers historical data access and live monitoring capabilities. Within the Nerve Centre, the system is mainly used as an OPC DA capable gateway, i.e. OPC DA server, for feeding the data warehouse of the Nerve Centre. The second data source of the data warehouse is machine controllers (PLCs). Dependent on the process, e.g. forming, the PLCs provide specific machine and process data as well as sensor data in a high temporal resolution (milliseconds). Examples of process data are the stamp position and its acceleration. In general, controllers employ vendor-specific communication protocols. For efficient data access of all machines, a gateway was selected that supports a large variety of protocols. In the context of the

[1] https://support.industry.siemens.com/cs/document/64850998/powermanager-v3-4-sp1?dti=0&lc=en-WW.

Nerve Centre, WinCC professional was chosen as gateway. In addition to the gateway function, the software also supports a data storage function. This enables access to all acquired data through WinCC client applications. The data that is made accessible by the WinCC gateway (forwarding only in case of value changes) is routed to a MySQL database using a Visual Basic script for persistent storage. The stored data can now be used for further modelling steps.

Model Layer

In order to derive knowledge, the raw data collected is processed within the scope of the model layer. This can be done using various approaches, such as agglomeration of data (e.g. statistics), simulations and their parameterization with real data, as well as using machine learning methods. In the sense of the visual analytics process, however, it is also possible to convert the raw data directly into visualizations, such as time series, without much preparation. Within the framework of the Nerve Centre, for example, this is possible for the collected process data of the machines of the technical centre (see Fig. 7.10—process data analysis). Here, modelling using the open-source software Node-RED only involves reading the data from the database and converting it into graphs. A monthly data export from the SENTRON powermanager is carried out for the analysis of historical energy data of the technical centre. The machine-specific energy data is transferred to an Energy Sankey (e!Sankey of ifu Hamburg) and used to calculate KPIs (energy consumption and energy costs per month and consumer group, e.g. technical centre and technical building services) and plot an energy breakdown. A machine learning use case is implemented by means of a machine state recognition based on energy data (details on this can be found in Chap. 4). The first step is to export a training data set from the MySQL database. Within the course of data pre-processing, this data set is partially labelled with its corresponding machine states. Since a semi-supervised learning algorithm (label propagation) is applied, a labelling of the entire data set is not required. This significantly reduces the manual effort involved in data pre-processing. The model trained by label propagation is then stored and can be read into the Node-RED software by the Node-RED contribution machine learning and deployed with live data. The current machine status of a system is shown as text, time series and status distribution. The live energy data is provided via WinCC through an OPC UA server. Node-RED functions as an OPC UA client. In the machine-specific dashboard, the live energy data is visualized similar to the process data besides the machine status information.

Visualization Layer

Table 7.5 summarizes the dashboard applications with regards to their spatial and temporal scale as well as possible knowledge insights (Figs. 7.11, 7.12, 7.13 and 7.14)

Table 7.5 Dashboard portfolio applied at a large-scale video wall

Application	Spatial scale	Temporal scale	Knowledge insights
 *Energy Sankey*	Factory	Minutes - months	- Consumer-specific energy consumptions - Clustering to consumer groups - Comparison with last periods(s) - Hot spot detection
 *Breakdown Analysis*	Factory	Minutes - monthly	- Grouped time series of energy consumptions - Hot spot and anomaly detection - Aggregated energy & cost KPIs
 *Energy Data Analysis*	Process	Seconds - hours	- Live and time series of power demand - Live, time series & distribution of machine state - Automated live energy & cost KPIs based on machine states
 *Process Data Analysis*	Process	Seconds - hours	- Live and time series of process data

7.7 Summary and Outlook

The chapter presents an approach to enhance Life Cycle Engineering workflows for automotive lightweight body parts based on principles of Visual Analytics. Two engineering scenarios have been explored—the support of the conceptual design stage as well as the development of innovative manufacturing processes. The Life Cycle Design & Engineering Lab (LCDEL) at OHLF objectifies the presented workflows. The LCDEL represents a permanent and evolving research infrastructure with the goal to further incubate and mature engineering methods and tools.

Beyond the presented case studies, LCDEL will serve as a platform for future stages of research on innovative automotive structures in the light of sustainable development. On a component level, this includes methods and tools to support the engineering of structural parts that integrate further functions such as electric, acoustic or

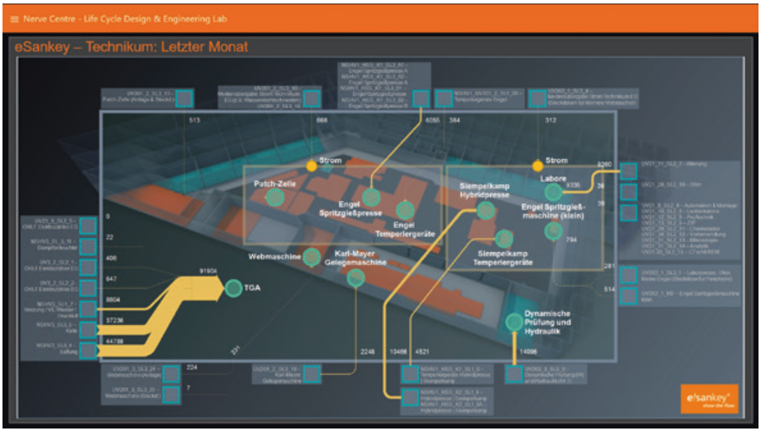


Fig. 7.11 Energy Sankey

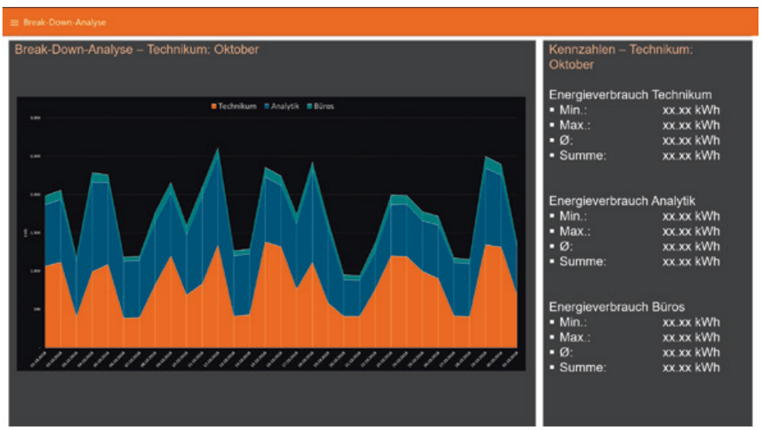


Fig. 7.12 Breakdown Analysis

thermal insulation capabilities. Further, the engineering scope will be broadened towards more systemic perspectives on innovative vehicles and their life cycles. This includes advanced approaches to link component-centred engineering at OHLF with further vivid and highly innovative domains. One example is the joint engineering of structural parts and vehicle drivetrains. Another major focus will lie on the derivation and translation of requirements from adapted vehicle use scenarios and operating models, e.g. changing lifetime distances in mobility-as-a-service.

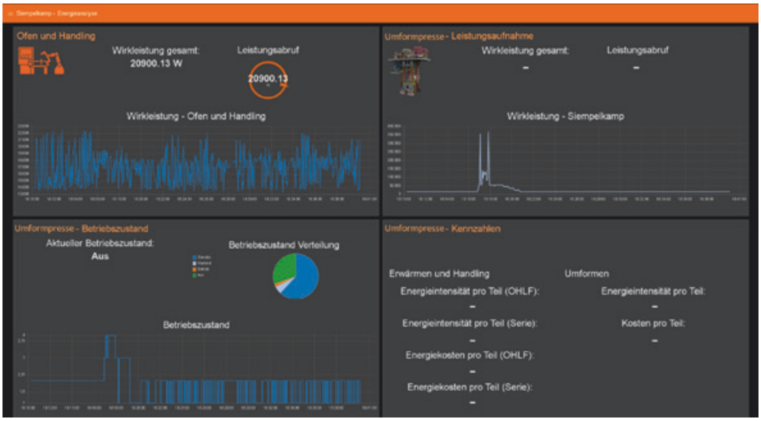


Fig. 7.13 Energy Data Analysis

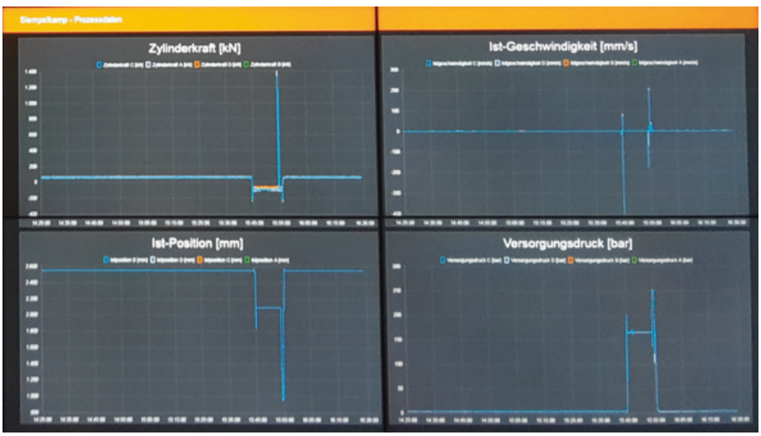


Fig. 7.14 Process Data Analysis

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