D2.1 A SET OF KPIS TO DESIGN FOR PRODUCTIVITY, RESOURCE EFFICIENCY, AND SAFETY

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ABSTRACT

This deliverable describes the developed performance indicators (PIs) and key performance indicators (KPIs) to design for productivity, resource efficiency, and safety together with guidelines for their applications. The report also describes the exemplary implementation of the performance indicators and key performance indicators on a few selected demonstration projects.

KEYWORDS

Data supported structural design, performance indicator, key performance indicator, knowledge database

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DISCLAIMER

ACRONYMS & DEFINITIONS

PI	Performance Indicator
KPI	Key Performance Indicator
PG	Performance Goal
DT	Digital Twin
EPD	Environmental Product Declaration: "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function" (International Organization for Standardization, 2006).
SBP	schlaich bergermann partner; ASHVIN project partner
WP	Work Package

ASHVIN PROJECT

ASHVIN aims at enabling the European construction industry to significantly improve its productivity, while reducing cost and ensuring absolutely safe work conditions, by providing a proposal for a European wide digital twin standard, an open source digital twin platform integrating IoT and image technologies, and a set of tools and demonstrated procedures to apply the platform and the standard proven to guarantee specified productivity, cost, and safety improvements. The envisioned platform will provide a digital representation of the construction product at hand and allow to collect real-time digital data before, during, and after production of the product to continuously monitor changes in the environment and within the production process. Based on the platform, ASHVIN will develop and demonstrate applications that use the digital twin data. These applications will allow it to fully leverage the potential of the IoT based digital twin platform to reach the expected impacts (better scheduling forecast by 20%; better allocation of resources and optimization of equipment usage; reduced number of accidents; reduction of construction projects). The ASHVIN solutions will overcome worker protection and privacy issues that come with the tracking of construction activities, provide means to fuse video data and sensor data, integrate geo-monitoring data, provide multi-physics simulation methods for digital representing the behavior of a product (not only its shape), provide evidence based engineering methods to design for productivity and safety, provide 4D simulation and visualization methods of construction processes, and develop a lean planning process supported by real-time data. All innovations will be demonstrated on real-world construction projects across Europe. The ASHVIN consortium combines strong R&I players from 9 EU member states with strong expertise in construction and engineering management, digital twin technology, IoT, and data security / privacy.

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1 INTRODUCTION

1.1 Background

ASHVIN develops digital processes that will allow for the seamless integration of all stakeholders within and across the design, construction, and maintenance of buildings and infrastructure. This will be achieved by possibilities for back- and forward information and knowledge flow through all stages of the product development process.

ASHVIN establishes design and engineering processes that can leverage experiences and lessons learned from past projects (evidence-based design). These processes can project the effects of design choices on the productivity, resource efficiency, and safety during early design stages. In the context of the ASHVIN project, means to collect data generated during the process of building design, construction, and maintenance and the transformation of this data to measurable performance indicators and key performance indicators should be established. The ASHVIN platform allows for real-time monitoring of these indicators related to processes in design, construction, and asset management.

This deliverable is part of WP2 and will describe a collection of performance indicators which help to assess and, later, improve the performance of a structure in the early design phase with respect to the key performance indicators

- productivity,
- costs,
- resource efficiency, and
- health and safety.

This report presents guidelines to derive these performance indicators from specific project-related data and how to set up a knowledge dataset based on data from past design projects.

An exemplary implementation of selected performance indicators on a demonstration project (#8 Footbridge in Germany) will show the applicability and flexibility of the methodology.

1.2 Aim and objectives

The idea is to specify and implement a structured, but also general and flexible, process, to define, derive and apply performance indicators (PI) and key performance indicators (KPI) for structural design. These indicators should allow assessment of the performance of a structure, help to understand the sensitivity of the indicators with respect to design changes and support an objective data-based decision-making process in the early design phase. The developed methodology will serve as a basis for an evidence-based design assistant (ASHVIN tool “BRICS”) and a generative design configurator (ASHVIN tool “GEN”).

The outcome should be:

- Set of KPIs and PIs to steer design activities.
- Guidelines how to define and derive PIs and how to apply them in the design process.
- A revision of past projects (footbridges, stadia) with respect to relevant PIs
- Implementation of the developed methodology using at least one example project.

1.3 Outline of the document

The report consists of six chapters. Chapter 2 introduces a guideline to derive performance indicators and key performance indicators from data to assess the design of the structure ("from data to dashboard"); it also presents a collection of design relevant performance indicators. These performance indicators serve also to calculate "knowledge datasets" based on data from past design projects. In chapter 3, the developed methodology is applied to a footbridge in Dortmund (demonstration project #8 Footbridge in Germany) which is currently being designed. The findings of this report are summarized and discussed in chapter 4. Finally, an outlook and future research ideas and tasks are presented in chapter 5. The literature referenced is listed in chapter 6. Finally, an example of a data source is presented in the appendix (chapter 7).

2 ASSESSMENT OF THE DESIGN OF STRUCTURES

2.1 "From data to dashboard" – a general guideline

The large amount of information that is generated during the design phase, is used to develop an objective and data-based assessment of the structure to understand the impact of possible design changes.

To arrive at this conclusion, one must first answer the following fundamental questions:

i. Which criteria is to be used to judge the design?
ii. How can one capture and measure these criteria?
iii. How does one judge whether a criterion is fulfilled well, or poorly?

The answers to these three questions can be given in abbreviated form with the help of a keyword:

i. Key performance indicators (KPI) are the main criteria to be defined by which the design will be judged.
ii. Performance indicators (PI) are several related and quantifiable sub-criteria that constitute a KPI.
iii. Performance goals (PG) provide a reference system for each performance indicator, which can be used to obtain a scale of assessment by comparison.

The application of these terms in the systematic and data-based assessment of the design of a building structure is presented below.

The research results from the TU1406 Cost Action project (Strauss, et al., 2016) , (Pakrashi, et al., 2019) and (Stipanovic, et al., 2017) served as a guideline for the chosen approach, both in terms of content and concept. However, the guidelines developed in this work in the area of inspection and maintenance of bridge structures can only be transferred to the design area to a limited extent. During construction and maintenance phases, performance can be assessed well with the help of measurement results; this is not the case in the design phase. In the design process, experience and tacit knowledge gained from the construction of similar structures are used.

In this report, a guideline is presented on how to come to assess a structural design and which variables are of interest. The parameterised design optimisation and automated decision-making process ("from design to decision") will be discussed in a later work package of the project (T2.3 Generative design configurator).

Figure 1 shows the flow of the assessment process ("from data to dashboard") in sub-steps. Although the process flow in the actual calculation of a KPI is from bottom to top, the elaboration of the conceptual framework from top to bottom makes more sense, i.e. one defines a target criterion in the form of a KPI, collects PIs that constitute the KPI, and considers which data has to be collected to calculate the PIs. Additionally, an illustration is given of how a benchmark can be created from existing project data that allows an assessment of the design.

The last step deals with the collection of the underlying data. This data is collected from the existing project or already executed structures and is the basis for the benchmark as well as for the current performance.

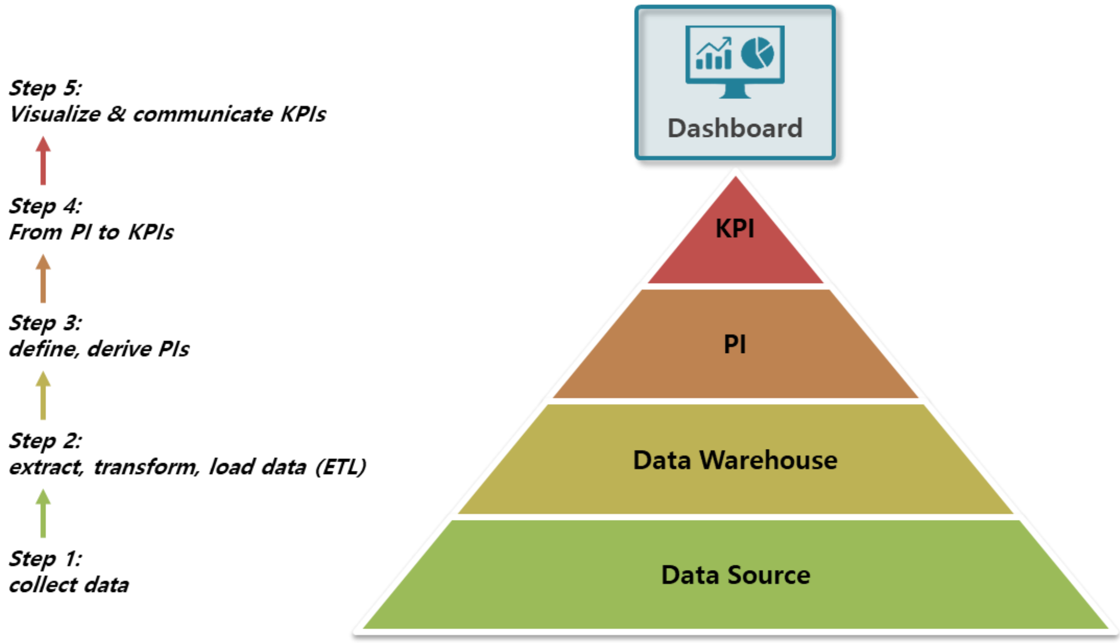

Figure 1 "From Data to Dashboard" - graphical representation of the approach

2.2 Key performance indicators (KPI)

2.2.1 Overview

With the help of key performance indicators (KPI), the assessment of a design is reduced to a few representative criteria and associated key figures, and the extent to which these criteria are met is indicated.

In the first step, the criteria to assess a building design must be established.

Ideas in this direction have already been elaborated (Schlaich, et al., 1997) in the field of engineering, with a focus on bridge structures. In the sense of a holistic and objective assessment of bridges, the following main criteria or KPIs were defined within the framework of a design competition:

- Structure and Design
- Functionality
- Comfort
- Environmental impact
- Efficiency and economic aspects

Each of these main criteria is made up of several sub-criteria; these sub-criteria, arranged in a tree structure (Figure 2), are referred to below as performance indicators, or Pis, in short.

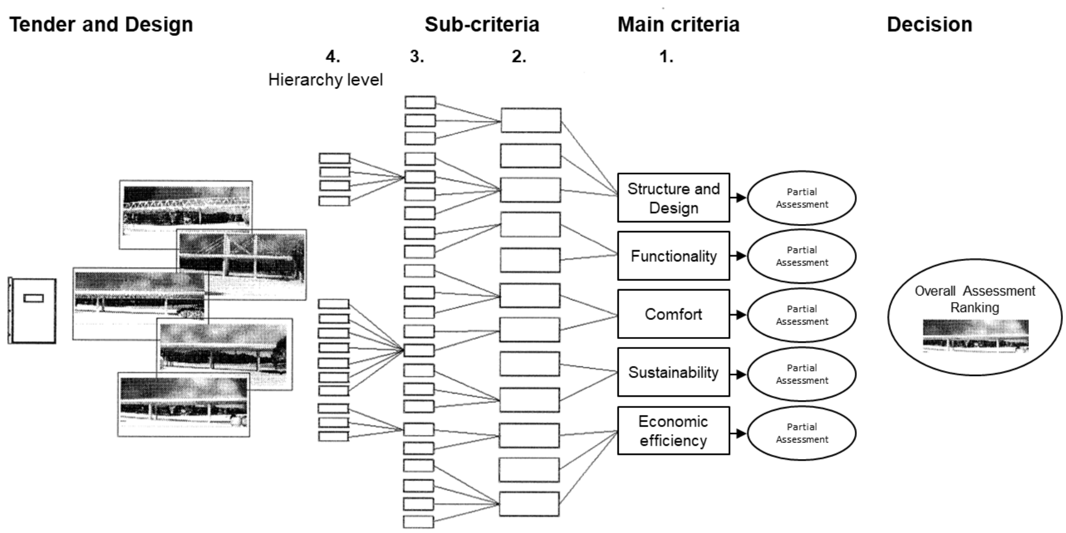

Figure 2 Assessment of bridges, main criteria (KPIs) and hierarchical structured sub-criteria (PIs) (Schlaich, et al., 1997)

The above KPIs are undoubtedly relevant for the design of building structures, but they are by no means the only possible KPIs.

The choice of KPIs, i.e. objectives manifested in key figures, is generally made depending on the project and the specifications at different decision-making levels.

2.2.2 Approach in the ASHVIN project

In this research project, four target criteria/KPIs for design, construction and maintenance were already defined in the proposal (Grant Agreement, Annex 1, Part B). These are

- Costs
- Productivity

- Health & Safety
- Resource efficiency.

For a better understanding of the terms used this report and those used in the proposal, the following different definition should be emphasised: the four target criteria listed above are referred to as KPIs in this report. The individual indicators that make up these KPIs are hereafter referred to as PIs.

The evaluated KPIs should be graphically displayed on a dashboard of the ASHVIN platform for each design solution. This visualisation

- allows for a quick visual comparison with other design variants,
- highlights potential benefits and likely pitfalls of the design variants,
- reveals possible sensitivities in the design regarding various parameters at a glance, and
- facilitates informed decision-making between possible options based on factual evidence.

Figure 3 shows a possible representation of the ASHVIN KPIs in the form of a radar graph (spider graph); other graphical representations are of course possible.

A rating scale has been plotted on the graph. How one arrives at this rating is still an open question. The idea is that the overall score is made up of the weighted sub-scores of the individual PIs.

Using the visualisation of the design assessment according to the KPIs, the structural assessment is completed. This part of the research project does not yet include automated decision-making based on the evaluation of the KPIs and/or an accompanying parameter-based design optimisation with regard to the KPIs.

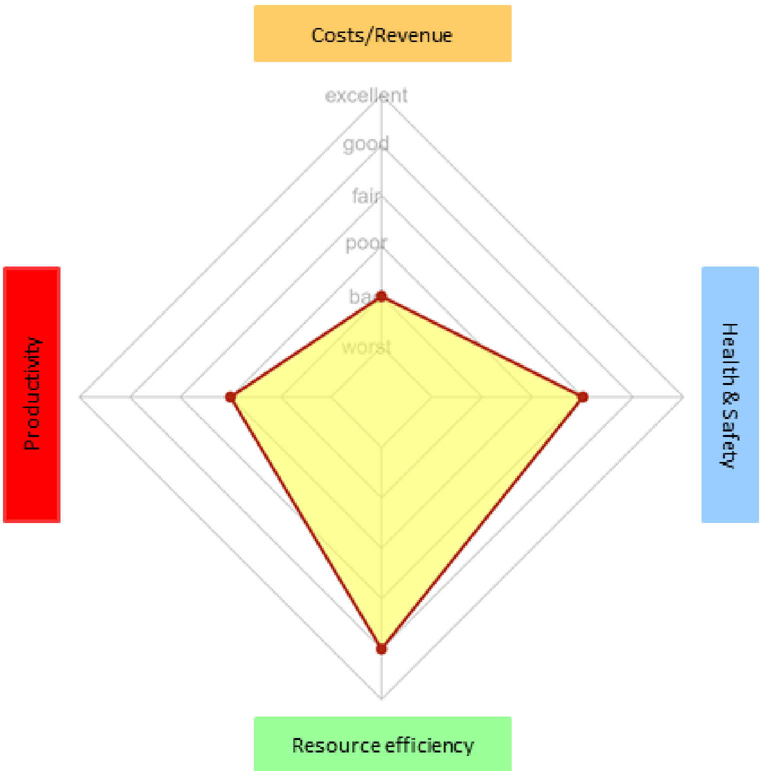

Figure 3 Exemplary visualisation of the ASHVIN KPIs using a radar/spider graph

2.3 Performance Indicators (PI)

2.3.1 Overview

Performance indicators are individual project-specific variables that are used to evaluate the design, construction or maintenance of a structure. These are either obtained directly, derived, or calculated from project-related data, general data and information and measured data, or inferred from the tacit knowledge of practitioners.

Figure 4 shows a list of possible PIs that are of interest in the context of the design, grouped by category.

Each PI is evaluated individually. The possibilities for setting a benchmark for evaluation are described in the following section. Some PIs are only evaluated according to whether they have been taken into account in the course of the design, e.g. whether safety management is enforced when lifting heavy components, or whether an award has been won with the design or not. This is not a numerical value, but a logical value.

The PIs are then assigned to a KPI. A PI can also be assigned to several different KPIs.

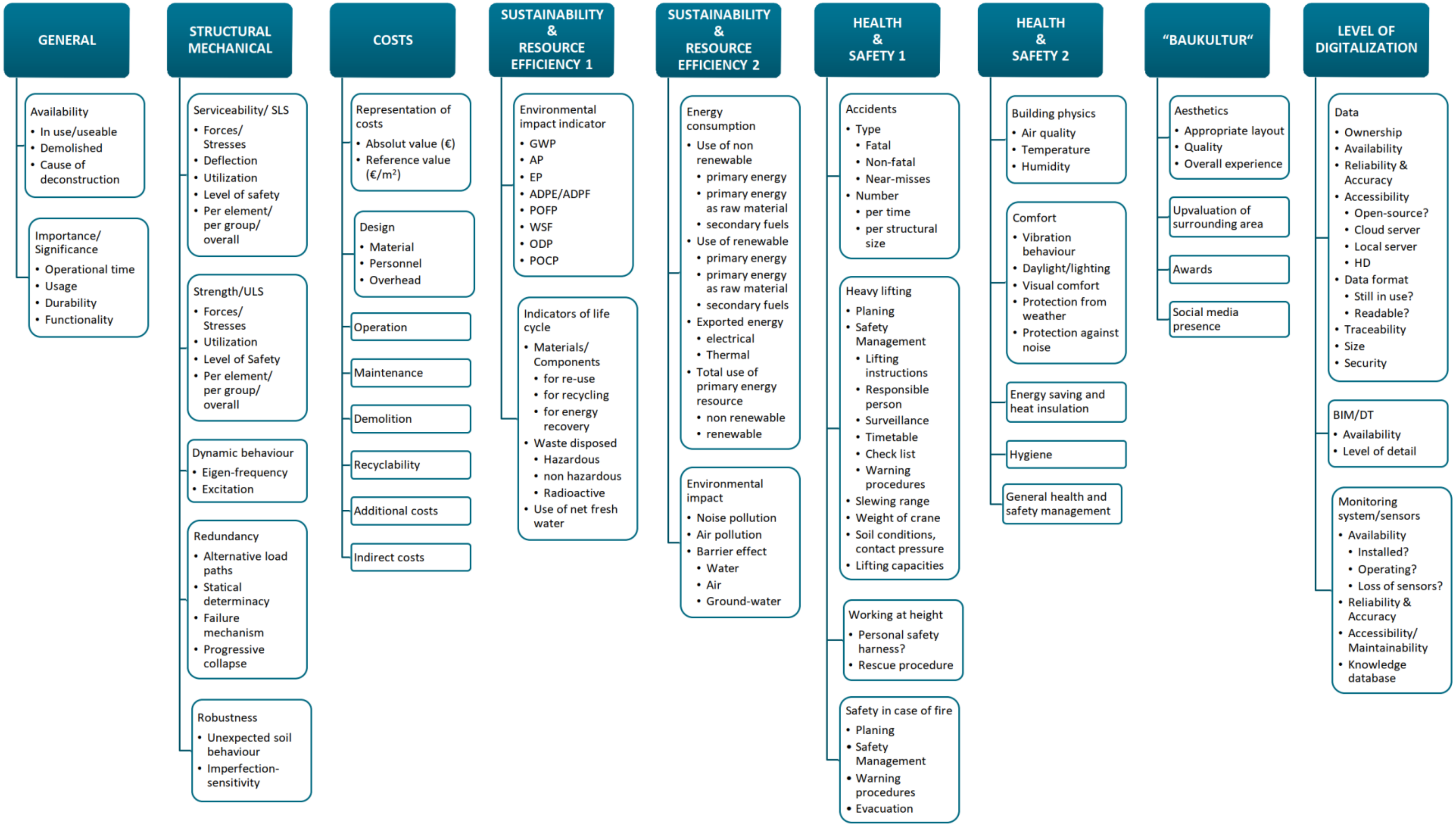

Figure 4 Collection of design relevant performance indicators (PIs)

2.3.2 Set of Design PIs - approach in the ASHVIN project

To limit the number of PIs for the design to a representative subset from Figure 4, PIs for the structure categories of footbridges and stadia roofs were selected for the exemplary implementation. For these two building categories, the available data was from several completed buildings designed by project partner sbp (schlaich bergermann partner), a structural engineering and consulting firm specialising in the design of light, minimal and innovative structures, such as membrane, glass, roof and facade structures, bridges, and cable structures.

To enable a comparison between different footbridges, the values of the PIs are normalised, i.e. related to a functional unit. For pedestrian bridges, this can be the area of the walkway, for example. The area of a roof can be used as a functional reference unit for stadia roofs. For this reason, some of the units listed below are always given per square metre.

The Design will concentrate on the PIs listed in Table 1 to 4; These PIs will be assigned to one of the four pre-defined KPIs and calculated for demonstration case #8 (Footbridge in Germany), which is currently being designed by the project partner sbp (Figure 9).

2.3.2.1 Costs

Performance indicators related to Costs and Revenue are shown in Table 1.

Table 1 KPI "Costs" - Design PIs

KPI	PI	Definition	Unit
Costs	Material costs (design)	Overall design/material costs	€/ m^2
	Personnel costs (design)	Overall design/engineering costs	€/ m^2
	Payback period	Payback period is the time it takes to cover investment costs and is usually considered to assess risks. Investments with a short Payback period are considered safer than those with a longer one.	Years
	Return on investment (ROI)	ROI enables the evaluation of the feasibility of an investment or the comparison between different possible investments. It is defined as the ratio between the total incomes/net profit and total investment of the implementation of solutions.	%

2.3.2.2 Productivity

Productivity related performance indicators are shown in Table 2.

Table 2 KPI "Productivity" - Design PIs

KPI	PI	Definition	Unit
Productivity	Personnel productivity (Design phase)	Overall design /engineering man-hours; reduction in overall design/engineering man-hours	h/m^2
	Personnel productivity (Construction phase)	Overall construction execution man-hours; reduction of production downtime and idle man-hours during construction	h/m^2
	Number of identified clashes	Each identified clash or error during the design phase save money during the construction phase. During the design phase the error/clash can be easily fixed. Clashes indicate which interferences are likely or where and/or how more than one part of the building collides or overlaps with another to cause conflict in the design, with the potential of incidents and impractical construction during project execution.	no. clashes/ building
	Number of open issues	Total number of open design issues at a given point in time	no. open issues
	Review and approval period	Average time to handle a review and approval of a deliverable and design changes	Days
	Structural performance	Allows to assess the structural performance of the whole structure or of structural components (group, single member) and serves as basis for future maintenance tasks. For example, knowledge of the utilisation of specific members as calculated during the design, allow a targeted assessment, which will raise productivity in the maintenance stage. It comprises of below listed PIs: structural adequacy, structural utilisation, structural redundancy, structural robustness.	%
	Structural adequacy	Ability of a structure to withstand design loads and resist destabilizing forces	%
	Structural utilisation	Utilisation = E_d/R_d (R_d...Design value of the resistance; E_d...Design value of effect of actions)	%
	Structural redundancy	A statically indeterminate structure is structurally redundant if there is continuity within the load path or an alternative load path possible.	%
	Structural robustness	Robust structures can withstand catastrophic events without being completely damaged to a dysfunctional state (EN 1991-1-7)	%

2.3.2.3 Resource efficiency

Table 3 highlights some resource efficiency and sustainability related performance indicators, most of which are indicators of life cycle and environmental impact indicators as defined in Environmental Product Declaration (EPD) databases.

Table 3 KPI "Resource efficiency" - Design PIs

KPI	PI	Definition	Unit
Ressource efficiency	GWP	Global warming potential; see https://www.environdec.com/indicators	CO2 eq kg/m^2
	AP	Acidification potential	SO2 eq kg/m^2
	EP	Eutrophication potential	PO43 eq kg/m^2
	ADPE	Abiotic depletion potential for non fossil resources	Sb eq kg/m^2
	ADPF	Abiotic depletion potential for fossil resources	%
	POFP	Photochemical oxidant formation potential (kg NMVOC eq.)	kg NMVOC eq. Kg/m^2
	WSF	Water Scarcity Footprint	m3 H2O eq
	ODP	Depletion potential of the stratospheric ozone layer	CFC 11 eq. kg/m^2
	POCP	Formation potential of tropospheric ozone	Ethen-eq. kg/m^2
	Materials/components for reuse	Percentage of material/components which can later be used for reuse	%
	Materials/components for recycling	Percentage of material/components which can later be recycled	%
	Hazardous waste disposed	Amount of hazardous waste generated from the project and its usage	kg/m^2
	Non-hazardous waste disposed	Amount of non-hazardous waste generated from the project and its usage	kg/m^2

2.3.2.4 Health and safety

A set of performance indicators to assess the health and safety aspects of a structure are listed in Table 4.

Table 4 KPI "Health and Safety" - Design PIs

KPI	PI	Definition	Unit
Health and Safety	Comfort: dynamic behaviour	Vibration behaviour and comfort; eigenfrequency and/or acceleration of bridge in comfortable range?	Hz, m/s^2
	Comfort: daylight/lighting		Rating (subjective or data based)
	Comfort: visualisation of walkway		Rating (subjective or data based)
	Comfort: slippery surface/walkway		Rating (subjective or data based)
	Safety Management	Installed? lifting instructions/guidance; responsible person; Surveillance; Timetable; check list; warning procedures, etc.	Yes/No/Incomplete [%]
	Number of accidents: fatal	A fatal accident is is defined as an accident that leads to an employee fatality during the course of performing work. The definition of a fatal accident depending on the time span between accident and death may also depend on the country in which it occurs.	no. of accidents
	Number of accidents: non-fatal	A non-fatal accident at work is an accident which a victim survives and may result in one or more days of absence from work.	no. of accidents
	Number of accidents: near misses	A near miss is an unintentional incident that could have caused injury, death, or damage, but was narrowly avoided. A near miss may be attributed to human error, or might be a result of faulty safety management in an organization.	no. of accidents
	Incident rates	Number of accidents in a given timeframe	no. of accidents per time or accidents per structural size

2.4 Performance goals (PG) and benchmarks

2.4.1 Overview

The specification or calculation of the PIs does not in itself enable an assessment. A separate benchmark is needed for each performance indicator. This reference or target system is herein referred to as a performance goal (PG). The PG can be specified by standards, certificates, recommendations, guidelines, or common agreed precedented knowledge, among others.

Precedented knowledge from past projects that are similar to the one being evaluated presents another possible frame of reference for benchmarking. The performance indicator for these projects is calculated to identify the range of values in which the results of the PI calculation can be expected, how much they scatter, where the mean value lies, what the common features, and unique identifiers might be, etc.

Once the benchmark is established, the value of the PI can be determined for the current structure. This value can then be compared with the data set to establish in which range it lies.

The collection of all data of a structure category, e.g. all footbridges, can be combined in a "knowledge dataset", as illustrated in Figure 5. This dataset contains all basic baseline data, the calculated PIs, all systematically processed data, and therefore serves as the basis for exploratory data analysis and for the definition of PGs.

In the course of time, this data set is enriched by all data from each further project of a given structural category. This dynamic change naturally causes shifts in the frame of reference derived from it.

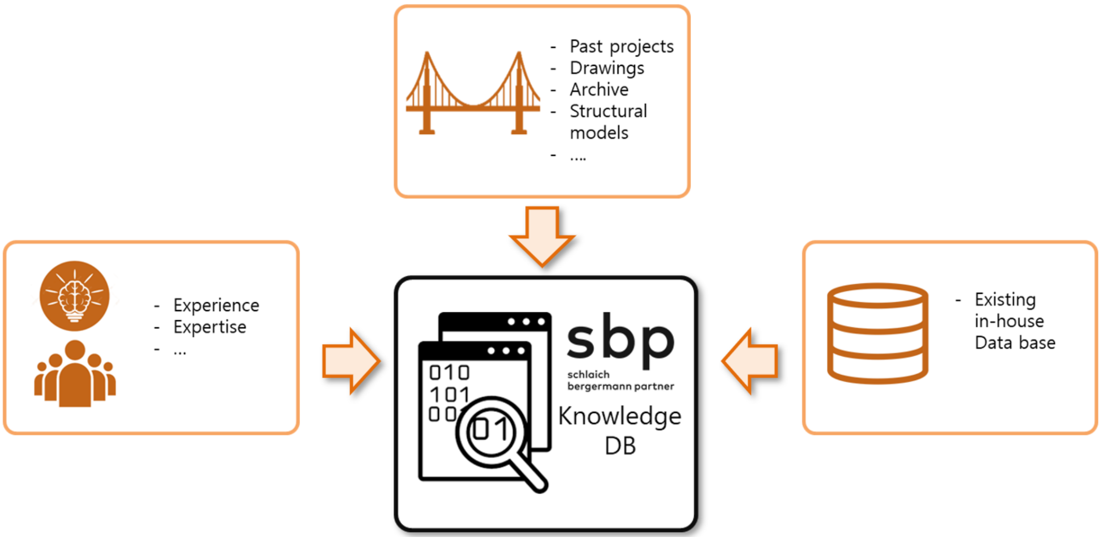

Figure 5 "Knowledge datasets": collection of PIs and basis data from former projects

2.4.2 Approach in the ASHVIN project

To obtain reference values of performance indicators for individual building categories and structural system types, the data from past projects designed by project partner sbp were collected, sorted and graphically presented.

Figure 6 shows the embodied carbon of pedestrian bridges as CO2-eq in relation to the area of the walkway (Tissot, 2019). The values given consider stages A1-A5 according to EN 15643-5:2017. The red line indicates the mean value. On the other hand, Figure 7 also considers Stages A1 to A5 for the embodied carbon calculation of the stadia roofs. Both figures sort the values by structural system type.

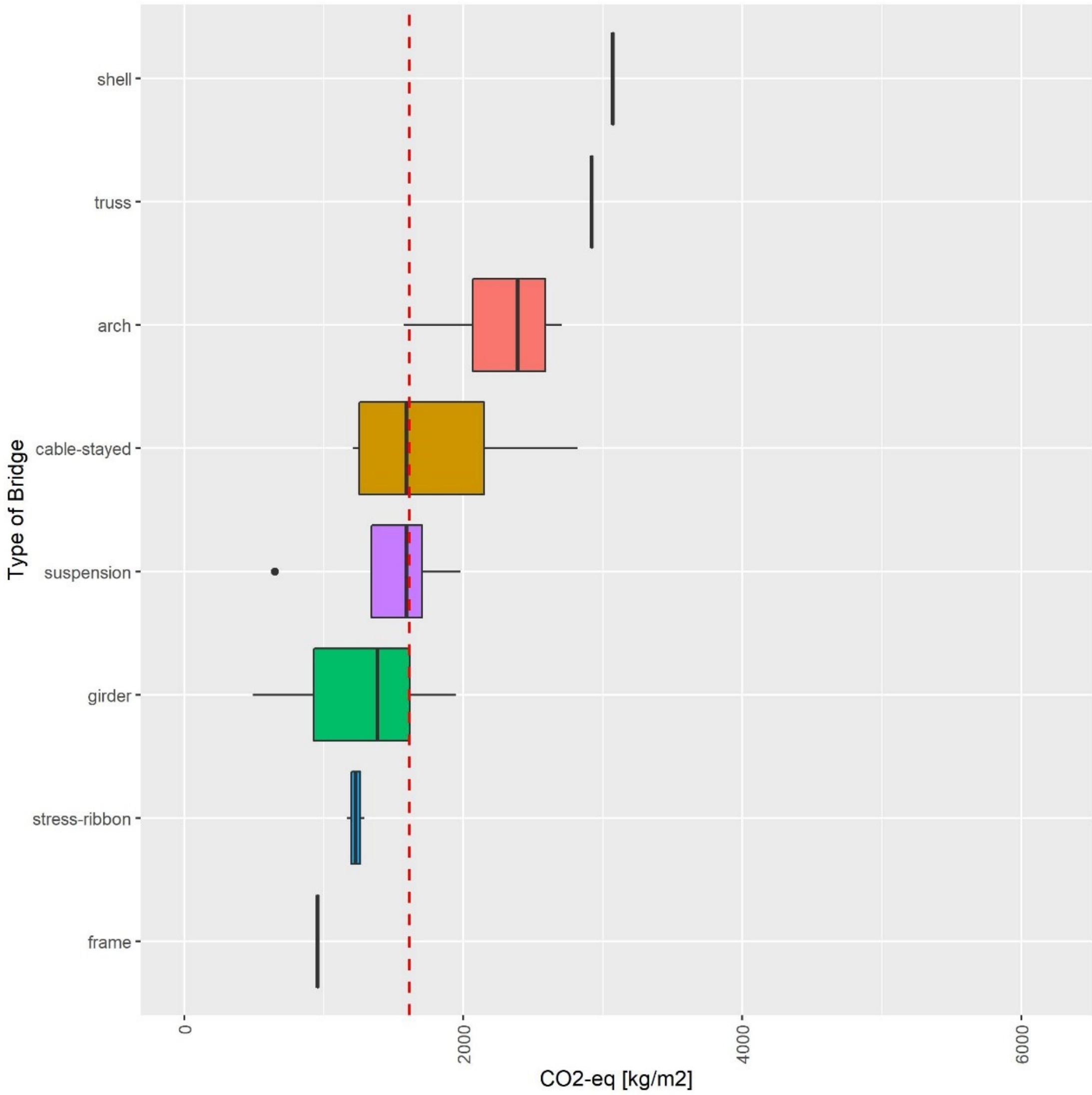

Figure 6 Embodied carbon (stages A1-A5) of footbridge types; (Tissot, 2019)

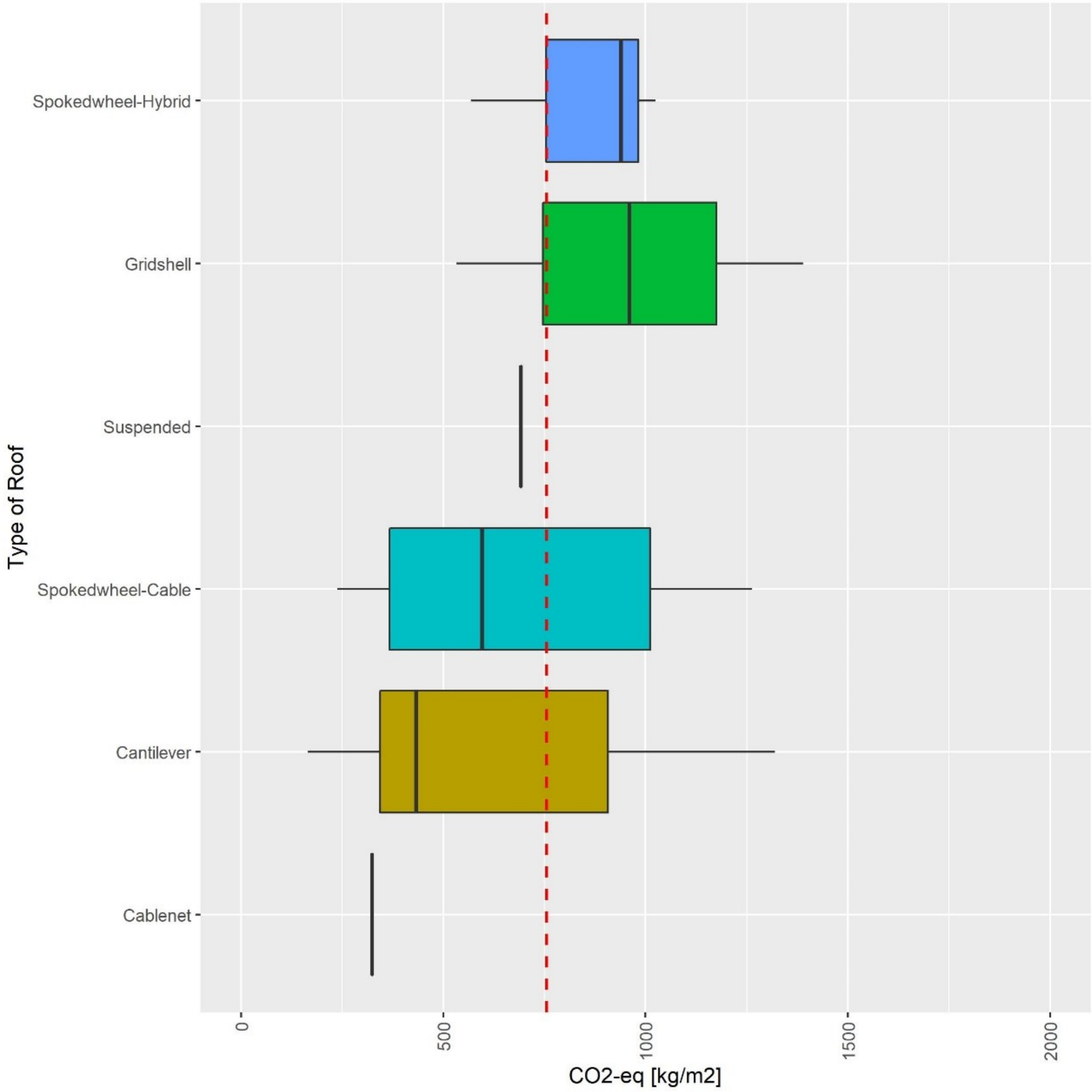

Figure 7 Embodied carbon (stages A1-A5) of stadia roof types

A guideline on how to collect and prepare the required project data is provided in the following two chapters.

2.5 Evidence-Based Data and Data Sources

2.5.1 Overview

All performance indicators are based on the collection and transformation of information into digitally available and processable data.

The required basic data can be divided into three main groups (Table 5):

- Project related/specific data,
- Project related/specific monitoring data and
- general, additional relevant data.

For the first group, the data sources include any project documents such as from contracts, specifications, CAD models, static calculations, accounting documents, invoices, diaries, bills of quantities, material schedules and quantity take-offs, project schedules, etc. The project-specific data sources are a wide variety of information sources whose data must often first be extracted from the respective documents, put into a unified form, ordered, and collected.

The second group contains only data obtained from measurements of the structure. This group of data is particularly important during the construction and maintenance of the structure. However, during the design phase, this project-specific data is often not yet available, and therefore plays a subordinate role.

But measured data from other comparable projects and any insights gained from them, which have already been prepared and are available in the form of knowledge databases, can very well be used already in the design. However, these knowledge databases are assigned to the third group, the general data. General data is usually mostly enriched by the tacit knowledge of field practitioners. Table 6 and the Appendix is an example of how such knowledge can be harnessed through having dialogues with experienced practitioners.

The collection of data from the last two groups is often problem-free, as existing data sets can be accessed.

This is the essential task in sub-step 1 "collect data", illustrated in Figure 1.

Table 5 Data Categories, Sources and Types

Category	Data source	Data Type
Project related/specific data	- Reports, contracts - Protocols, memos, presentations… - Models (CAD, BIM, Structural mechanical models) - Images, photographs - Drawings, Sketches - Project timeline - Invoices, documents (accounting department) - Already existing project datasheets - …	"Extreme data": - Complex, diverse, multi-lingual data - Dispersed data sources - sparse/missing/ insufficient data - extreme variations in values - engineer's tacit knowledge and experience
Project related/specific monitoring data	- Measured environmental conditions on site - Measured displacements and deformations - Measured damage & deterioration - Installed instrumentation, - Inspection reports - Monitoring reports - Condition assessment reports - Data loggers - …	- IoT protocols - Measurement data
General Data	- Standards, Guidelines, Specifications, … - Publications, books - URL - Experience, Knowledge database - Various external datasheets and databases (material, products, meteorological, environmental, social media …) - Interviews with project practitioners - ….	- Database file, .csv, .pdf, .xlsx, .html, .db, .sql, …

2.5.2 Project data sheet

To collect the project specific data, a project data sheet was created for each structure category (bridge, building, façade, roof, etc.). An exemplary and general composition of a project data sheet with a hierarchical structure in main and subcategories, which can be used as a basis for various building categories, is shown in Figure 8.

Identical structure categories have a uniform data sheet with the same data subcategories. The categories are to be understood as a guide, not as a rigid prescription. With the infinite variety of building designs, space must always be provided for individual special features or object-specific information.

The creation of a data sheet is divided into the following sub steps:

- Organise the uniform structure of the data sheet, i.e. define general and building type-specific categories and determine the associated data format
- Obtain information from various sources and fill in the data sheet
- Check consistency and correctness of the data

Without computer-assisted data mining, the systematic collection of building data from these data sources is labour-intensive, costly, and error-prone. Therefore, automated acquisition of selected data is in progress within the framework of the project.

In the course of data collection, individual subcategories may be considered in more detail due to new fields of interest and, thus, new categories are defined. With this intentional expansion of the project data sheet, it is recommended not to group all information into a single data sheet, but to split it up according to the categories. These project data sheets can be unambiguously assigned to each other and united via the project number (relational project data sheets).

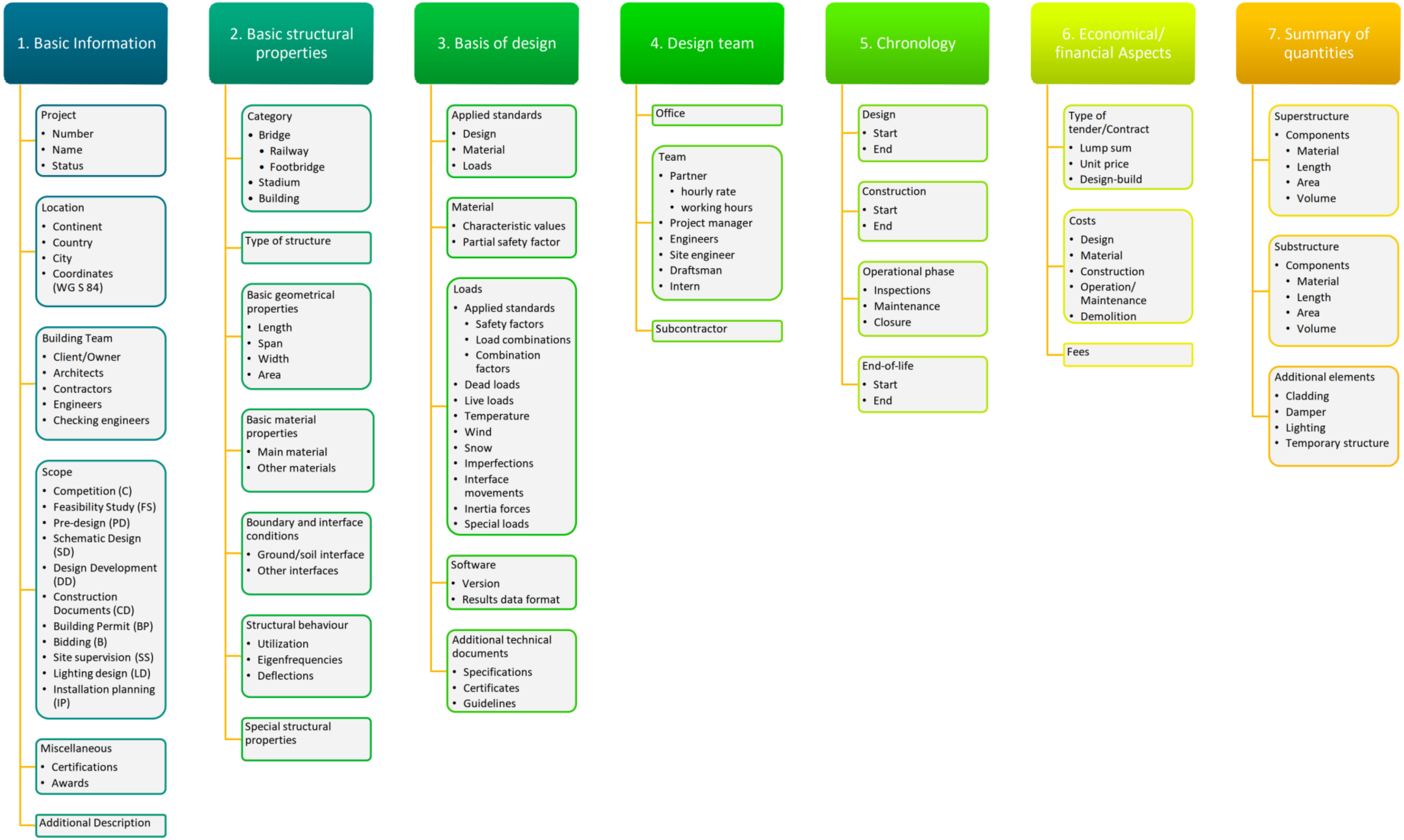

Figure 8 Exemplary structure of a project data sheet – categories and subcategories

2.5.3 Approach in the ASHVIN project

Data from structures designed by schlaich bergermann partner was used in the ASHVIN project. Since all data comes from projects of the same structural engineering office, it is naturally tendentious and subjective due to the office's field of activity in light structures and special construction. Due to the limited number of projects, the data set is sometimes representative with limitations especially for future predictions.

The following observations were made when analysing the existing project data:

- Many categories had been created but were only partially filled with data.
- Missing information was no longer available or could only be obtained with unjustifiable effort.
- Data was deliberately not collected, or only collected to a limited extent, because of its sensitive content.
- In addition to a central data collection, there were other similar or identical collections that differed more or less from each other in terms of content.
- Some information was no longer up to date.

All these critical observations can be explained by the amount of heterogeneous data sources, which are often not available in digital form.

The first task in the project was to supplement and correct the existing data and to collect it in a uniform project data sheet according to Figure 8. In order to limit the amount of data, the data collection was restricted to two structure categories, pedestrian bridges and stadia roofs. In each main category only a part of the subcategories given in Figure 8 were filled in. The selection was made in anticipation of the performance indicators to be calculated later.

2.6 Organized datasets - data warehouse

2.6.1 Overview

The aim of data collection is to use these data sets to calculate project-relevant PIs and, in a next step, to explore them through comparative data analysis and to make a statement about the performance of a design with regard to a design aspect.

It makes sense to combine the heterogeneous data sets from the different sources and store them in a central target database (data warehouse) in a uniform format. This standardised process, which is also called an ETL (Extract, Load, Transform) process, takes place in three steps:

- Extraction: Extract data from the existing data records, e.g. read the data from a project data sheet, and import it into a workspace for further processing.
- Transformation: The data is then transformed according to the specifications of the target database. The transformation can include the following sub-steps:
    - Data cleansing
    - Sorting data into columns and rows
    - Combining and merging
    - Quality control and data validation
- Load: In the last step, the extracted and cleaned or transformed data is stored in the central target system.

The uniform format facilitates working with the data, e.g. visualisation and explorative data analysis.

2.6.2 Approach in the ASHVIN project

A pedestrian bridge data set and a stadium data set were created from the individual project data sheets. The extraction of the data from the individual project data sheets, the transformation of the data and the storage in a pedestrian bridge or stadium data set was carried out automatically with the programming language R. R is a language and environment for statistical computing and graphics.

You can represent the same dataset in multiple ways. However, the structure of the datasets in the target database follows the concept of the "tidy" dataset. There are three interrelated rules which make a dataset tidy (Wickham, 2014):

- Each variable must have its own column.
- Each observation must have its own row.
- Each value must have its own cell.

This specific dataset structure makes it easy to apply tools for data analysis and data visualization, which significantly facilitate visual data exploration.

The ETL process can also be skipped, in which case, however, productivity is lost later during the data analysis or visualisation due to additional manipulations of the datasets which are often necessary and sometimes cumbersome. Furthermore, additional manipulations of the data sets can also lead to errors which are overlooked or even generated during the manipulation.

3 DEMONSTRATION PROJECT #8_ FOOTBRIDGE IN GERMANY

3.1 Overview

The City of Dortmund is planning to replace the existing Lindemannstrasse pedestrian and cycle path bridge, which connects Max-Ophüls-Platz with the forecourt of the Dortmund Trade Fair Centre. The bridge crosses the Rheinlanddamm, a highly frequented inner-city main road with six lanes. In a central location in the Dortmund city area, it provides a pedestrian link from the city center to the most important event centers of the town, the Messe Dortmund area, the Westfalenhalle and the adjoining football stadium.

The existing structure from the 1950s has gradients of far more than over 6% and, according to the recognised rules of technology, is not barrier-free. Therefore, the city of Dortmund is planning a barrier-free replacement of the Lindemannstraße bridge over the Rheinlanddamm.

The new bridge (Figure 9) directly connects the two squares in the same way as the existing structure, replacing the previous steep ramps with stairs. The stairs are supplemented by wide cantilevered ramps ("loops") that overcome the height level, whereby the freely cantilevered loops create a new, widely exposed view, especially on the side of the trade fair forecourt.

The bridge design envisages the superstructure, the stairs and the supports as a monolithic, jointless steel construction. The continuous superstructure has a total length of approx. 210m and is regularly supported at intervals of approx. 50-60m by splayed V-shaped supports. The span of the superstructure is approx. 35-48m in free length and approx. 14-17m in the support area. The cantilever of the loops from the column axis to the abutment is approx. 17.5m from the support axis to the abutment (Figure 11).

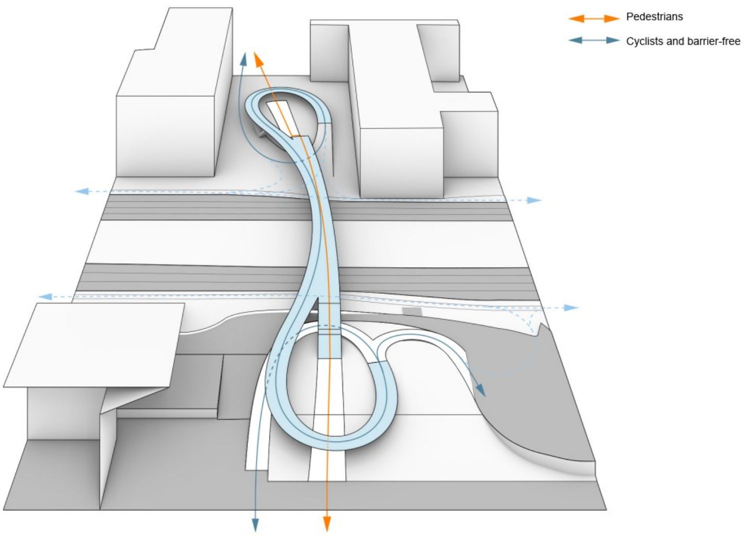

Figure 9 Footbridge over the Rheinlanddamm in Dortmund - Overview

The timetable of the project is as follows:

- Start of planning (August 2020)
- Tendering and award of contract (October 2021)
- Deconstruction of the existing bridge (August 2022)
- Construction of the new bridge (June 2022)
- Completion (November 2023)

Figure 10 Footbridge over the Rheinlanddamm in Dortmund - Plan view

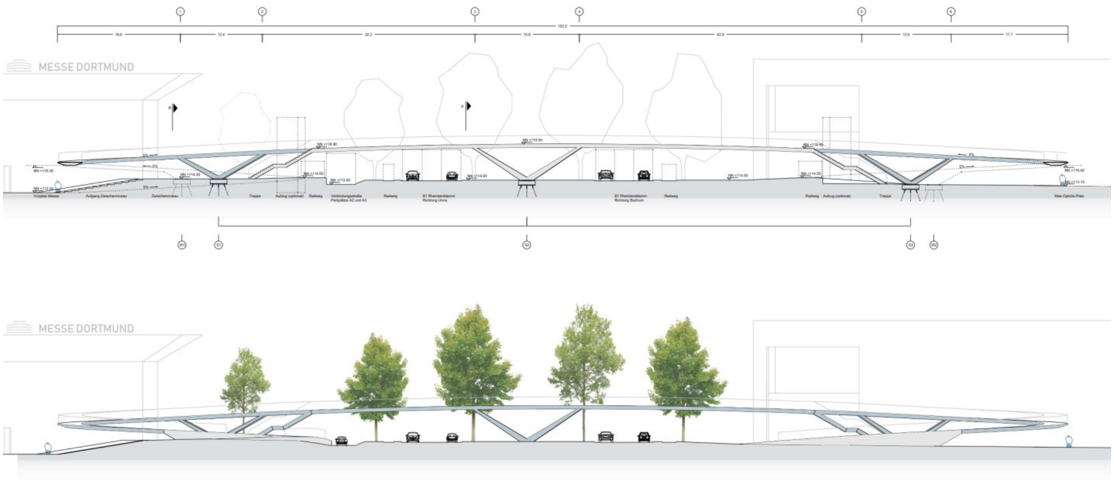

Figure 11 Footbridge over the Rheinlanddamm in Dortmund - Elevation view

3.2 Key performance indicators and performance indicators

The design of the bridge is to be assessed regarding the four defined KPIs:

- Costs
- Productivity
- Resource efficiency and
- Health and Safety

Two performance indicators, personnel productivity and the embodied carbon, are calculated and presented using the example of the pedestrian bridge in Dortmund. These two PIs are assigned to the KPIs "Productivity" and "Resource efficiency" respectively. (Figure 12). One reason for the small number of PIs is that the reference data is yet to be obtained and then elaborated for past projects. Nevertheless, the concept "from data to dashboard" elaborated in chapter 3 can be demonstrated with these two dissimilar performance indicators.

This time, in reference to Figure 1, the procedure is bottom-to-top: first all the required data is collected and structured. Then, the PI is calculated. To create the frame of reference (PG), the same procedure is also applied to past projects.

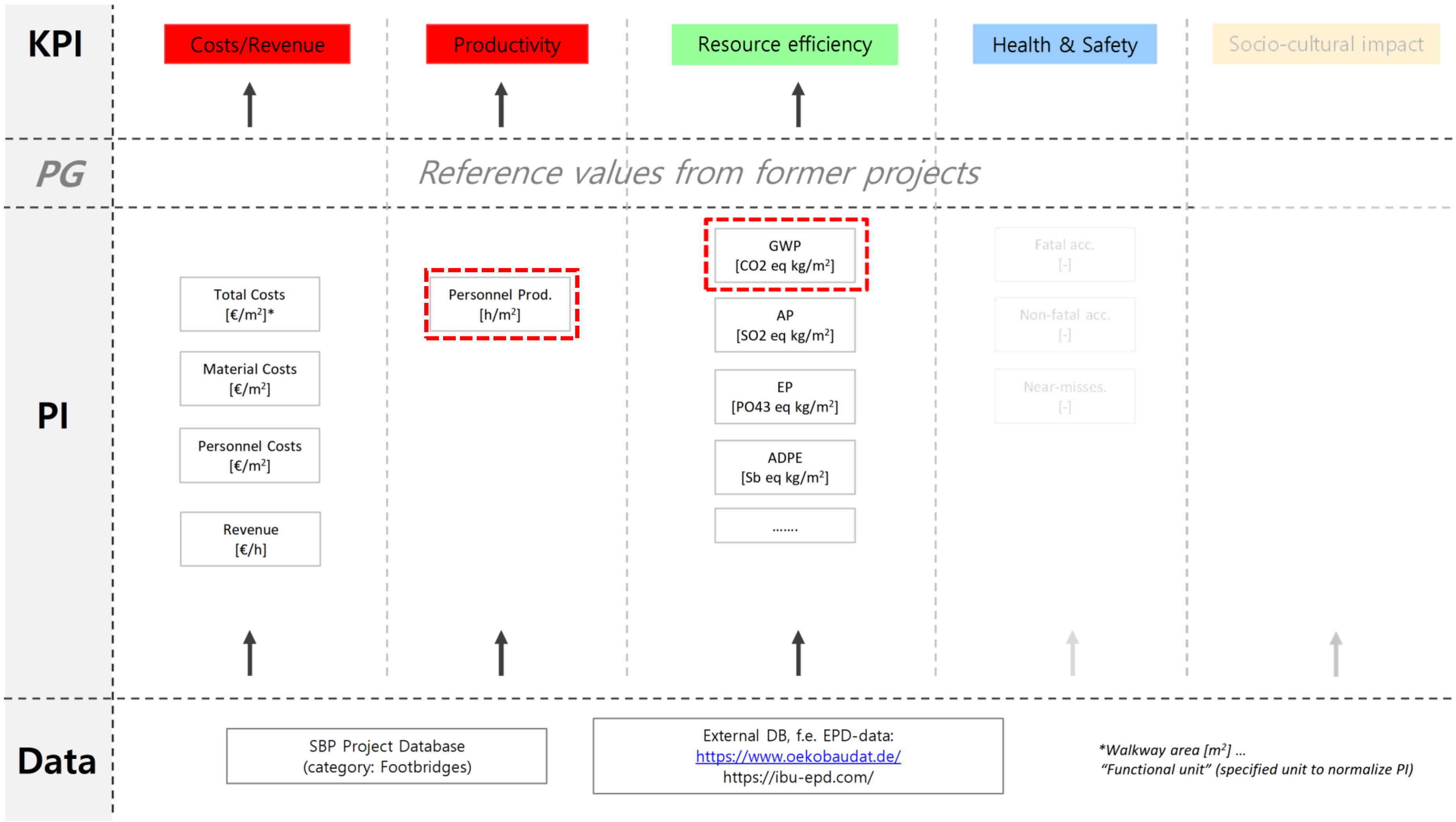

Figure 12 Footbridges - KPIs and selected PIs

3.2.1 Embodied carbon calculation

Three sets of data are needed to calculate the embodied carbon of the bridge and assess it in comparison with projects already carried out:

- The calculated embodied carbon values of past projects are already stored in a "knowledge dataset"; the calculated values and their dispersion per pedestrian bridge type are shown in Figure 6.
- To calculate the embodied carbon from the individual components of the bridge, a product database (environmental product declaration, EPD) with CO2 values for component and material groups is necessary.
- The bill of quantities of the pedestrian bridge in Dortmund - as detailed as available at the current design stage - is the basis for calculating the CO2 footprint.

For a procedure that is repeated frequently and easily in the course of the design, a small program was written that reads the masses from the static model (Finite Element Method program Sofistik) and calculates the CO2 footprint with the selected EPD data sets. To compare this value with the other footbridges, it is divided by the area of the walkway. This value is plotted on the graph in Figure 6, and then provides a visual ranking or rating of the current design (see Figure 14).

The workflow for the embodied carbon calculation is shown in Figure 13. This procedure can be easily transferred to all performance indicators.

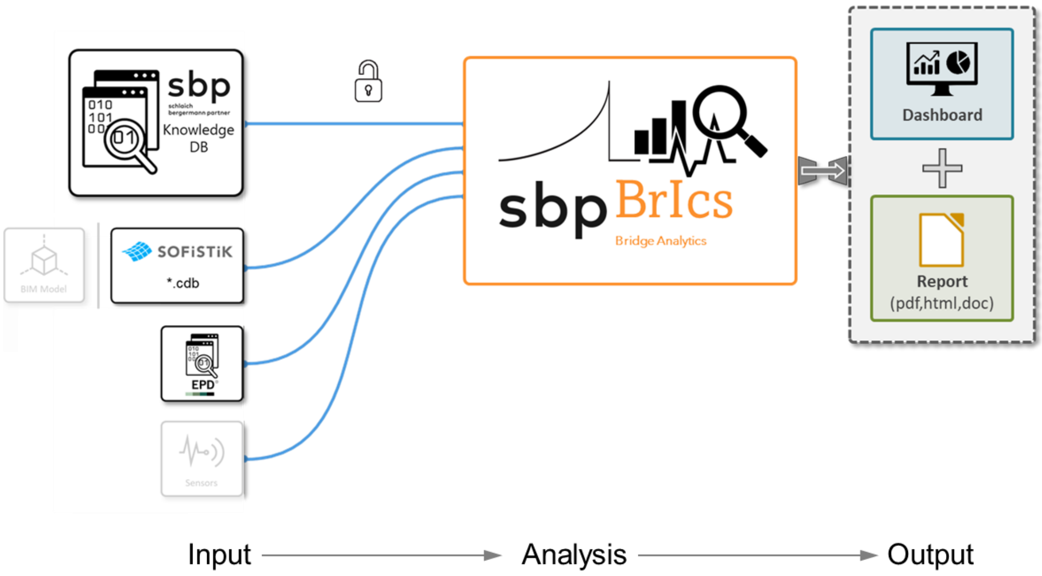

Figure 13 Automated calculation of the embodied carbon of a footbridge - „From data to dashboard"

There is a commercial software that embeds the embodied carbon calculation in the BIM workflow. The advantage of the streamlined procedure presented here is that the designing engineer can already calculate the embodied carbon from the first models without using the intermediate step of updating a BIM model, and can keep an eye on the embodied carbon throughout the design.

Another advantage is the connection to the corresponding knowledge dataset; this bundles the experience and knowledge from comparable models and already provides an orientation in the design as to the order of magnitude of the embodied carbon to be expected.

This automated calculation procedure including the associated knowledge database is to be applied to all desired performance indicators in a similar form and integrated into the ASHVIN platform as a tool.

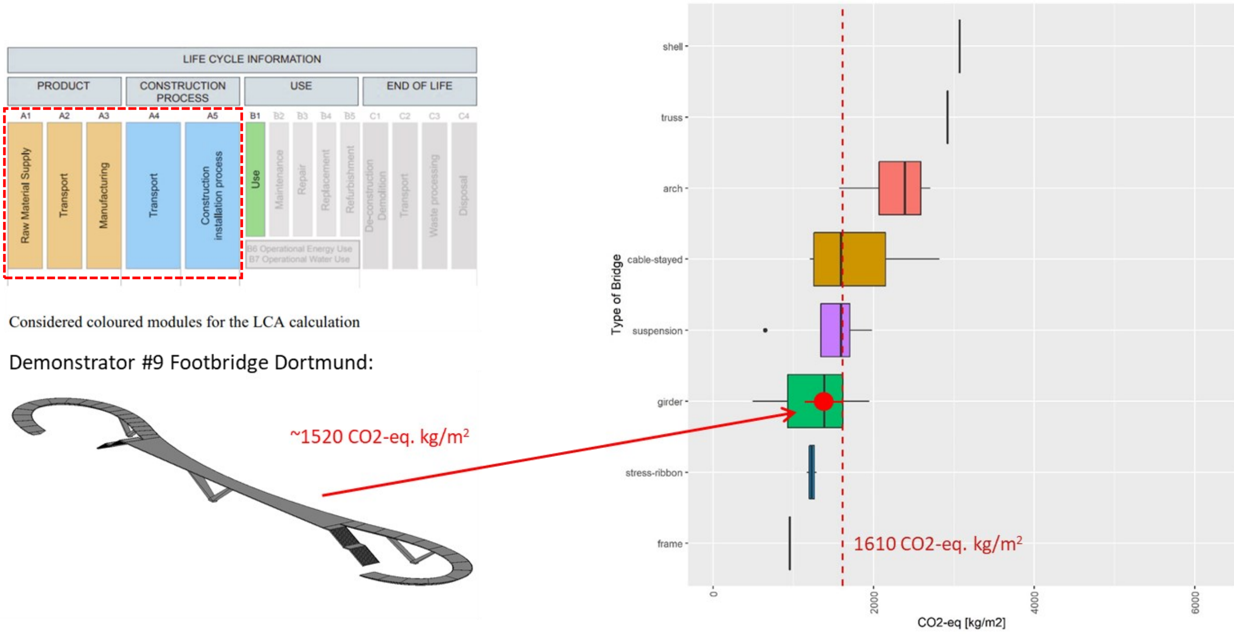

Figure 14 Carbon Footprint of the bridge in an early design phase

3.2.2 Productivity

The previously described procedure can be similarly applied to other PIs using a knowledge database. Figure 15 shows the required design/engineering man-hours per pedestrian bridge design grouped by bridge type.

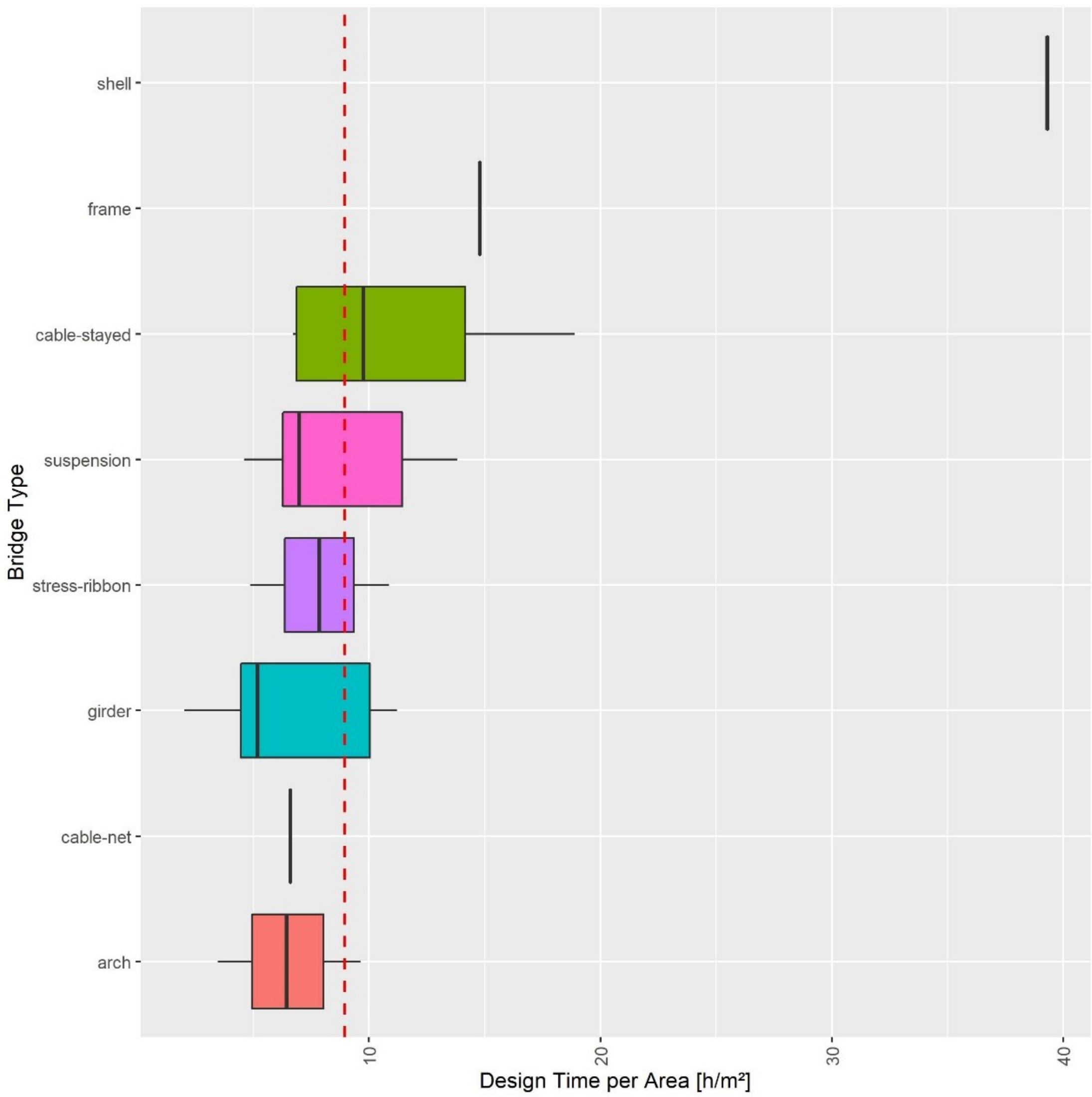

Figure 15 Design/engineering man-hour per footbridge type

4 SUMMARY, CONCLUSION AND DISCUSSION

4.1 Summary

This report contains a collection of performance indicators (PIs) relevant to the design of engineering projects and mapped to the four pre-defined key performance indicators (KPIs),

- Costs,
- Productivity,
- Resource efficiency, and
- Health and Safety.

The KPIs are main categories that have already been defined as the four ASHVIN targets from the proposal. The PIs are sub-components from which the KPIs can be calculated, and whose evaluation results from the evaluations of the individual PIs.

Moreover, a general guideline (generic framework) was presented on how to carry out a data-based assessment of projects in the course of the design phase with the help of the defined PIs ("from data to dashboard"). Values from past projects serve as a reference benchmark or assessment framework. This collection of project data and its storage in an ordered form in a "knowledge database" is a fundamental building block of the whole procedure.

The procedure, from data collection to PI and comparison with existing projects, was presented using the embodied carbon indicator of a pedestrian bridge in Dortmund as an example.

This shows the efficiency and flexibility of this developed concept: it is so simple that it can be immediately transferred to other performance indicators of various types. Each PI - from the underlying data to the calculation - forms a small, self-contained, and independent building block ("brick"). The collection of these bricks results in a digitised wealth of experience. Through further data analysis, possible cross-connections can be revealed, and insights extracted from these data in the future.

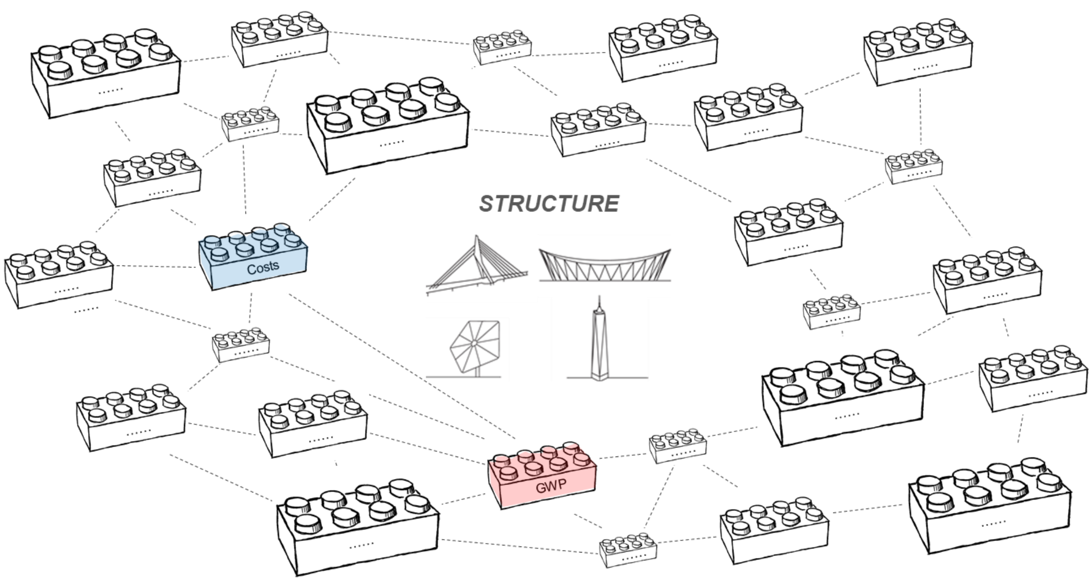

Figure 16 "bricks" concept - schematic illustration

4.2 Conclusions & Discussion

Structural design is an experience-based, rational, but also creative process that has always been supported by collection of data and experience. A new aspect of the approach presented here is the clear structuring and the data-supported holistic consideration of the most diverse aspects of the design. This insight into a wide range of decision variables not only serves to improve the design regarding the defined key performance indicators, but also increases the understanding of the design engineer, his productivity through the availability of knowledge databases, and facilitates the communication of design decisions.

In this task of WP2 the premise was still that the data is only supportive, and the decision is still made by the designer, or the design team. This anticipates some of the work done in Task 2.2 “Evidence based design assistant”. Automated data-based decision-making is part of the next project task (Task 2.3. “Generative design configurator”). With a focus on sustainable design, this has been investigated by (Mathern, 2021) and recently published. A completely automated design is undoubtedly sensible for standard structures or standardised structures (e.g. motorway overpasses). However, for individual structures with a strong desire for architectural expression, the full automation of the design and shaping should also be viewed critically.

It is also an open question how subjectively assessable qualities of structures can be captured by this strongly objective data-based assessment process. Whereas the four KPI criteria of costs, productivity, health and safety, and resource efficiency are essential, they are too restrictive and inhibit the assessment of a good structural design. Design aspects as depicted in Figure 2 (Schlaich, et al., 1997) and (Schlaich, et al., 2008) are completely ignored in the selected key performance indicators. However, this claim to completeness in the qualitative evaluation of a structure is not made within the framework of the project; the ideas developed, however, create a flexible and expandable framework in which these aspects could also be included later. In Figure 12, for example, a column has already been provided for the KPI "socio-cultural impact".

One difficulty was and is the procurement of the relevant project data for the calculation of the PIs. Due to the heterogeneity and scattered nature of the data, this step is extremely time-consuming. An automated and targeted data collection must be developed.

In the proposal, it is envisaged that conclusions can be drawn from past projects about productivity and safety on the construction site or during the maintenance phase (“a well-chosen set of exemplary past design projects will be revisited according to how different design options did affect later on-site productivity, resource efficiency, and safety”). It is difficult to organise meaningful data that only allow an initial statement or assessment of this influence within the design phase. This data - if available at all - is to be requested from the construction companies carrying out the work.

The cross-phase data flow between design, construction, and maintenance within the framework of a digital twin, as envisaged in the ASHVIN project, can help to strengthen this data and information flow between the individual protagonists of a project, to possibly answer the question in the future as to which decisions in the design have which effects in the further project phases.

5 OUTLOOK AND FUTURE RESEARCH

From the work done so far, new ideas and questions have arisen that are to be answered in the next tasks of WP2.

5.1 Data mining

A major gap has become apparent in the existing or missing project data and its procurement and organisation. The computer-aided procurement, systematic storage and automated quality control of project data is essential for the establishment of an internal office project database of different performance indicators, a "knowledge database".

It is also an open question how to enable the flow of data between project phases to evaluate a design beyond the design phase in a data-driven way.

5.2 From PI to KPI

In the above process for evaluating a design with regard to selected KPIs, two essential questions remain unanswered:

- How to calculate a KPI from several PIs? Idea: Multi-Attribute Utility Theory (MAUT) method?
- How is the rating scale for each PI determined? Uniform, or PI specific? How are these ratings of the individual PIs combined into an overall KPI score?

5.3 Tool development

The KPIs and PIs are the basis for the next work steps, Task 2.2 "Evidence based design assistant" and Task 2.3 "Generative design configurator". The tool "BRICS" (the name is short for BRIdge analytiCS, but also because it is based on the “bricks” concept briefly outlined above) is at the centre of this; the following is to be carried out:

1. a systematic analysis and assessment of the current design regarding selected PIs, the defined KPIs and in relation to existing project data ("knowledge database") and
2. automated decision-making with accompanying design optimisation ("from data to decision"), based on a parameterised model structure.

The workflow is shown in Figure 17.

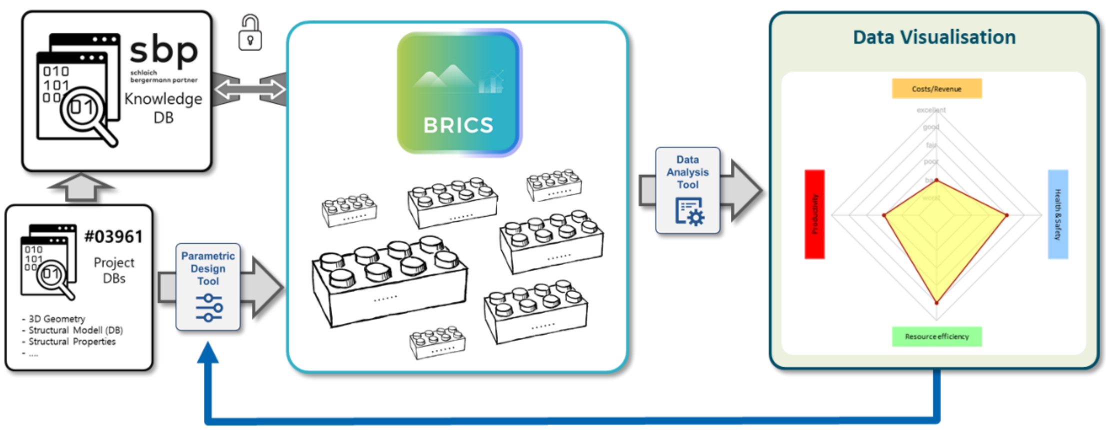

Figure 17 Data supported KPI driven parametric design workflow

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7 APPENDIX – EXAMPLE OF TACIT KNOWLEDGE AS A DATA SOURCE

Tacit knowledge is an implicit data source which can be harnessed to compliment traditional data collection and design processes in engineering.

Table 6 highlights the details and valuable insights gained from the technical interview and further population of a checklist by one of sbp' s experienced site managers. A truncated questionnaire checklist, based on the ASHVIN grant agreement and ASHVIN cloud resources, was used as a guide during the interview. The four KPI relevant for the ASHVIN project were discussed including what is required generally, the specific requirements, tools used, and finally how tracking of the factors can be done. The specific requirements are further enriched with actual examples of sbp projects which are part of the database to inform the evidence-based design for Task 2.2.

Some specific details may not be easy to capture and these have been entered as "not applicable" (n/a) for the sake of completeness in the Table 6. Also some *Inferences from the interview are included, as ideas for completeness.

*Table 6 Example of Tacit Knowledge as a Data source (Note:*Interferences from the interview)*

ASHVIN KPI	Requirements	Specific requirements (e.g., Example of sbp Projects)	Tools	How the factors can be tracked in each of the project phases		
				Early design (i.e. Pre-design and Preliminary design)	Detailed design	Construction
Productivity	Having a realistic basis for the design	Project-specific loads and loading types which satisfy usability requirements (e.g., Footbridge crossing from the main train station to the southern end of Kiel Fjord inner harbour)	*Tuned mass dampers (TMDs), *Sensors	An optimal design solution is chosen by 1. Brainstorming solution options 2. Consulting with suppliers 3. Reconsidering alternative options 4. Selecting the best option as choice to be constructed (The best choice is always a 'compromise' to achieve the overall project goal)	*not applicable (n/a)	Progress monitoring: Used to track the progress if it is as expected, or faster, or slower
		Member interconnections e.g., welded or bolted (e.g., Bridge crossing harbour and connecting historic city park)	*n/a		*n/a	*Practicable interconnections between members
		Structure which ensures an overall even distribution of the loads	Codes	Use design codes as basis for the engineering design		*n/a
		Adequate detailed studies and sufficient planning for the project (e.g., Bridge crossing harbour and connecting historic city park, and Mahlbusen Bridge with two steel bridges)	*n/a	*Satisfactory address of all technical requirements including future forecast scenarios	*Number of revisions leading to the final design	*Executable design
	The form (shape) of concrete members	Details of concrete members dictate the type of form work used (e.g., Bridge with a homogeneous image)	*n/a	Early on-boarding of architects enables an easier structural system	*n/a	*n/a
	Cast-in-place structural members	Geometry of the parts of the engineering structure	*n/a	*n/a	*n/a	*n/a
	Prefabricated structural members / beams	Weight of members to be lifted	*n/a	*n/a	*n/a	*n/a

ASHVIN KPI	Requirements	Specific requirements (e.g., Example of sbp Projects)	Tools	How the factors can be tracked in each of the project phases		
				Early design (i.e. Pre-design and Preliminary design)	Detailed design	Construction
	Adequate load-carrying capacity of each construction member	Members attain minimum acceptable limits to pass test trials	Test trials, Design codes	*Fewer errors recorded from design runs	*Fewer failed tests	*n/a
	Adequate carrying-capacity of all equipment	Good operable condition of all construction equipment	*n/a	*n/a	*n/a	*Reduced down-time and equipment breakdown
	Design for minimal handling and mobility	Minimal haulage distances	*n/a	*n/a	*n/a	*Travel time per truck
		Minimal movements around the site	*n/a	*n/a	*n/a	*n/a
		Minimum parts of detachable members	*n/a	*n/a	*n/a	*n/a
Resource efficiency	Most efficient roof structure with an equal distribution of loads among all members	Faster load transfers to the load bearing members and foundations (e.g., Observation bridge, S-curve crossing bridge, Urban pedestrian bridge)	*n/a	*n/a	*n/a	*n/a
	Optimized material selection to ensure minimal dead loads	Optimize design by using add-ons (e.g., tuned mass dampers) to enable slender sections rather than heavier structures (e.g., North Bridge, The multi-span bridge at the Werrekuss, Footbridge across the Am Kochenhof street)	TMDs	*Reduced weight of total dead load	*n/a	*n/a
	Satisfactory to meet client's preferences	Within budget cost	*n/a	Bill of quantities for different profile options are compared to see which influence each different profile may have	*n/a	*n/a
		Within the site constraints (e.g., within limited space available in a built-up environment) (e.g., Two bridges ('Train Station North' and 'Heilbronner Strasse'), Drahtbrücke' (wire bridge) in Kassel)	BIM		*n/a	*n/a

ASHVIN KPI	Requirements	Specific requirements (e.g., Example of sbp Projects)	Tools	How the factors can be tracked in each of the project phases		
				Early design (i.e. Pre-design and Preliminary design)	Detailed design	Construction
	Type of material (e.g., wood, steel, concrete,)	Material sizing e.g., how big the parts of the members are (e.g., Deutsches Museum München Bridge)	*BIM	Early on-boarding of architects influences choice of material e.g. wood	*n/a	*n/a
		Unit weight or density of the material	*n/a	*Embodied carbon		
Safety	Reduced incident rates	Safety is mostly the Contractor's responsibility to ensure	*n/a	*Early on-boarding of contractors		*Follow-up with contractors
		*Design for minimal handling and mobility		*Clash reports and safety scenarios	*Number of discrepancies, clashes and safety scenarios	*Incident rate records
		*Comprehensive planning to ensure project safety	*Using 'virtual' drills to simulate scenarios	*Number of 'virtual' incidents for the scenarios		
	Adequate carrying-capacity of all equipment e.g., cranes, forklifts,	Crane capacity should exceed maximum weight of members and materials	*Catalogues		*n/a	*Equipment idle time
	Adequate load-carrying capacity of cables for footbridges	Cable capacity should be adequate	*n/a	*n/a	Positive results of the test trials	*n/a
Cost	Having the project bills of quantity real-time	*Quantities takeoff	BIM	*Rough asset cost estimation based on comprehensive market surveys and analyses	*Detailed cost estimation based on analyses	*Expenditure checked against income
				* Asset cost estimation	*n/a	*n/a
	Materials schedules	Details on how the material is handled – whether fabricated or bolted, is important (e.g., Deutsches Museum München Bridge)	*Material take-off schedules	Comparisons with other projects to see current market situations	The most cost-effective design option is developed	*Realistic materials used for construction
		Choice of desirable quality options	*n/a	*n/a	*n/a	*n/a

ASHVIN KPI	Requirements	Specific requirements (e.g., Example of sbp Projects)	Tools	How the factors can be tracked in each of the project phases		
				Early design (i.e. Pre-design and Preliminary design)	Detailed design	Construction
	Materials specifications	Cost of materials	*BoQ	Bill of quantities (BoQ) estimates	*	*
		Adequate market surveys and sufficient planning for the project	*n/a	*Realistic materials selected suggested for the design		*Minimal deviations between budget and expenditure
	Optimized material selection to ensure cost-effectiveness	Use blend of materials for cost-effectiveness (e.g., use of TMDs can result in cost savings of the superstructure) (e.g., Deutsches Museum München Bridge)	*TMDs	*Significant cost savings calculated when bled of materials is used		*Optimal overall cost for the project