

## Categorized Findings from Evaluation Interviews (Chapter 6)

No.	Findings	Interviewees
Main Findings		
	11 out of 12 interviewees agreed that the solution presents a good way to bridge design and construction by using an integrated data environment and bringing the existing data in a suitable format to the site, where both site planning and management can benefit from the improved control and transparency of the TCI utilization, leading to a more lean and safer management of the construction site --> Less waste of time, money, recourses; more space on site, improved productivity and safety	11  Client 1, TCI provider 1, Contractor 1, 3, 4, Consultant 2, 3, 4, 5, 6, 7
	Contractor and TCI provider addressed the importance of integrating TCIs into the planning and management effort of a construction project as they significantly impact the time, costs and quality of a project and reduce waste --> Better planning and transparency benefits all parties involved in a project	5  TCI provider 1, Contractor 1, 2, 3, 4
	Automatic generation of TCI utilization by using and integrating existing project data is targeting a niche in construction which is not yet fully optimized	7  Client 1, Contractor 4, Consultant 3, 4, 5, 6, 7
	Approach of developing a data model for each construction project and use it for calculations and generating other value along the project development (for the whole life-cycle of a building) has a big potential and can be applied to many different areas, not only for formwork (e.g. general for most TCIs, project change management, heater sizing, automatic planning of reinforcement, prefabricated building elements, etc.)	2  Consultant 5, 6
	<b>Benefits</b> 1. Client: No direct benefit, but reliability of the contractors offer, better overview, less time and cost overruns 2. Contractor: Transparency and control over TCI utilization to improve the construction site planning & management 3. TCI provider: Precise number of items for each project to better plan stock and distribution, focus on complex structures, where automatic calculation is not applicable, proactive role with consultancy service in a project to address needs and requirements	12  All
	Obvious productivity increase and safety improvement as a secondary effect due to more transparency, control and lean management on site	10  TCI Provider 1, Contractor 1, 3, 4 Consultant 2, 3, 4, 5, 6, 7
	Solution offers a tool for the automatic planning of standardized formwork elements (given some assumptions), and provides the construction site with a transparent, integrated and location-based TCI-utilization plan that can be used to better plan and manage the construction activities related to simple in-situ wall structures --> Has to be further tested in a pilot project to reduce the amount of uncertainties and quantify the benefits	12  All
	Manual input of data, active tracking of TCIs on site with IoT-sensors and the integration of other TCI types are mentioned as general further developments of the solution	-  -
	Data integrity is a very important aspect in such an integrated and data-driven process and requires a QA-process to ensure that the input data complies with the specifications	5  Contractor 2, Consultant 3, 4, 5, 6
	Standardized ontologies must be established to describe the building data in its holistic context in order to ensure success of the solution	5  Consultant 2, 3, 4, 5, 6
	<b>Centralized approach:</b> Creating a solution-integrated and more advanced TCI engine which is able to calculate the precise	3  Contractor 1, Consultant 3, 7
	<b>Decentralized approach:</b> Outsource the calculation engines towards the different TCI provider who act as consultants for their specific product. TCI supplier receives the required project data and provides the demand of his products with the use of an advanced calculation engine as well as the service of planning and managing the items on the project	5  TCI Provider 1, Consultant 2, 4, 5, 6
	Easy accessible information for people who actually use the data in their work (dashboard for project manager and mobile application for the construction workers) and by that, solution reaches all relevant stakeholder	11  Client 1, TCI Provider 1, Contractor 1, 2, 3, Consultant 2, 3, 4, 5, 6, 7
	Integrate the created knowledge and transparency of the TCI utilization to site planning in order to optimize the site layout and logistics and enable a lean management	5  Contractor 4, Consultant 2, 3, 4, 5
	As the contractor benefits the most from implementing the solution, the business model should be created for him. A contractor with a Design&Build Contract has the whole value chain under them is able to control the data flows and require certain specifications from the parties involved and therefore, easily implement such a solution	5  Contractor 1, 3, 4, Consultant 4, 6
	Linked Data project delivery vision where all stakeholders generate and own their data, but provide their product information as a consultancy service to the linked project environment where it is integrated into the data model --> Decentralized nature of the project delivery will be the future when the focus will go more towards the data model and not the software solution	3  Consultant 2, 4, 5

0 Current practice on construction projects			
	<p>From the perspective of consultants and one contractor, TCIs are only considered in a very primitive and manual approach in which the demand might be estimated as a percentage of the total costs or with a rough and Excel-based calculation from a model-extraction</p> <p>--&gt; Based on this estimation, the elements are ordered from the supplier (TCl overstock or shortage on site)</p> <p>--&gt; Lack of TCI planning and monitoring on construction sites (No precise information which items are needed when and where)</p>	5	Contractor 4, Consultant 2, 3, 4, 5
	<p>In the perspective of most contractors, TCIs are considered in the site planning and management. However, there is no standard and automated way of doing this and it depends a lot on the contract, size and type of project in which level of detail they are planned and integrated into site management</p> <p>--&gt; In small project or where no data is available, TCIs are only considered with a rough estimation</p> <p>--&gt; For projects with a site model and structured building data, TCIs can be integrated in the site planning in order to optimize production workflow</p> <p>--&gt; Only one contractor used an integrating solution that is able to automatically quantify TCI demands from the model data</p>	3	Contractor 1, 2, 3
	<p>General tendency of site planner to order much more TCIs than needed in a specific period in order to ensure a consistent construction flow and minimizing the risk of resource shortages</p> <p>--&gt; Main driving force of the TCI quantification is to ensure that the schedule can be followed, leading to over dimensioned TCI orders to ensure that the TCI demand is met at all times</p> <p>--&gt; During the project, the estimation is adjusted and either more items are ordered in short notice or items are returned</p>	6	TCl provider 1, Contractor 1, 4, Consultant 2, 3, 4
	Missing transparency of which TCIs are needed when and where (no planning and monitoring) --> Items get lost or stolen	5	Contractor 1, 4, Consultant 2, 3, 4
1 Benefits			
A	General		
	Everyone in the production chain of a building project will benefit from an early planning of TCIs and a better collaboration and management of the construction site due to the gained transparency	1	TCl provider 1
	<p>Solution presents a good way to bridge design and construction by using an integrated data environment and bringing the existing data in a suitable format to the site, where both site planning and management can benefit from the improved control and transparency of the TCI utilization, leading to a more lean and safer management of the construction site</p> <p>--&gt; Less waste of time, money, resources; more space on site, <b>improved productivity and safety</b></p>	11	Client 1, TCl provider 1, Contractor 1, 3, 4, Consultant 2, 3, 4, 5, 6, 7
	Fascinating solution that tries to solve a real and complex problem in the construction industry with an open standard approach	3	Consultant 2, 4, 5
	Automatic generation of TCI utilization by using and integrating existing project data is targeting a niche in construction which is not yet fully optimized	5	Consultant 3, 4, 5, 6, 7
	Use of a very generic perspective (data modelling in construction projects with Linked Data) on a very narrow problem (formwork planning & management)	1	Consultant 5
	Early consideration of TCIs in project planning (Integration of TCI-Information and supplier expertise in the site & logistics planning) --> Planning the construction workflow in advance to improve decision making and a continuous and efficient production with a forward-looking and lean approach	4	TCl Provider 1, Contractor 1, Consultant 4, 6
	Approach of developing a data model for each construction project and use it for calculations and generating other value along the project development (for the whole life-cycle of a building) has a big potential and can be applied to many different areas, not only for formwork (e.g. general for most TCIs, project change management, heater sizing, automatic planning of reinforcement, prefabricated building elements, etc.)	2	Consultant 5, 6

B	Client		
	No direct benefit of the solution	12	All
	Reliability of the contractors offer (also less claims) as TCI-related parts are quantified with a thorough and transparent calculation, based on the tender material and not based on a untransparent and rough estimation	8	TCI provider 1, Contractor 1, 3, 4, Consultant 2, 4, 5, 6
	Better and updated project overview and more transparent construction site, reducing risk and uncertainty	9	Client 1, TCI provider 1, Contractor 1, 3, Consultant 2, 3, 4, 6
	Due to better planning, higher chance of following the schedule without cost and time overruns	6	TCI provider 1, Contractor 1, 3, Consultant 2, 3, 7
	Generally higher awareness of safety on the construction site through integration of more aspects on the site planning and the generated detailed TCI information on a task level	2	Consultant 6, 7
	Due to less items and a better planning on site, the client might end up with a smaller construction site, which facilitates the process of project approval and reduces the costs and difficulties of setting up a construction site	1	Consultant 7
	If the client has high requirements and expectations on the construction site planning regarding productivity and safety, such a solution would guarantee a good site planning and provide a transparent and quantified proof of the site manager to comply with the clients requirements --> also for the client to meet safety regulations for construction sites (e.g. scaffolding requirements in dense urban cities) --> Client can also require an early consideration of the TCI planning and site logistics management in pre-design if such a solution would be on the market	2	Consultant 4, 5
C	Contractor		
	Automatic planning of TCIs adds great value in terms of <b>transparency</b> and <b>control</b> over the TCI utilization as all resources can be planned in advance and the construction <b>site layout and logistics</b> can be planned and managed accordingly (at least for simple structures in big in-situ concrete projects regarding formwork) --> Early Stage Assessment of TCIs (Contingency budget regarding TCIs and their management can be reduced a lot --> According to <b>Consultant 4</b> , there is a big discrepancy of the estimated contingency budget for TCIs and the actual number, TCIs contribute to the costs) --> According to <b>Contractor 4</b> , the main benefit would be the saving that are generated by the dynamic stock consideration with reduced items on site leading to less rent and less waste of valuable storage space	10	TCI Provider 1, Contractor 1, 2, 3, 4, Consultant 2, 4, 5, 6, 7
	Early stage assessment of TCI requirements --> The better and earlier TCI planning is integrated into a project, the better the site planning can benefit from the transparency regarding TCI utilization and save money and time on site	8	Client 1, TCI provider 1, Contractor 1, 3, 4, Consultant 4, 5, 6, 7
	<b>Evaluate</b> and compare TCI provider <b>bids</b> by running the solution with a default TCI set or with the actual product of the TCI provider, which he provides in the bid material	2	TCI Provider 1, Contractor 1
	<b>Order precise amount</b> of TCIs from the supplier in advance based on the calculated TCI utilization plan	4	TCI Provider 1, Contractor 1, 2, 3, Consultant 7
	<b>Proactive</b> consideration of TCIs for the contractor with <b>less reliability</b> on supplier and higher certainty that the items on site meet the TCI demands throughout the project --> Contractor can save a lot of money as he has the knowledge of what he needs and does not only rely on the estimation of the supplier	3	TCI provider 1, Contractor 4, Consultant 7
	Contractor can easily use the solution and, automatically and in real-time, gain knowledge about which items are currently in use, what is the current stock on site as well as which items are needed in the future. Information is always up-to-date as the system considers changes in the building model as well as the project schedule (e.g. from progress monitoring) --> <b>Site transparency</b>	5	TCI Provider 1, Contractor 2, Consultant 2, 4, 5
	Dynamic supply of TCIs to the construction site (just-in-time) and <b>lean site management</b> on site based on the transparent utilization plan reduces the amount of elements that are stored on site which is directly reducing the costs of rent of the planned items as well as the use storage space on site --> As most of the cost are based on the handling of the items on site (storage, logistics, installation, dismantling), the main cost benefit lies in the <b>reduction of resource hours</b> , spent to get the TCIs from the state of storage to the utilization and back.	7	TCI Provider 1, Contractor 1, 2, 3, 4, Consultant 6, 7
	Solution allows to <b>optimize</b> the whole <b>production flow</b> and to have a more efficient and <b>lean management</b> process of TCIs --> With more <b>control</b> and <b>transparency</b> of the construction site logistics, time and cost of rent and handling can be reduced a lot --> <b>Transparency --&gt; Control --&gt; Better Planning --&gt; Lean Site Management --&gt; Efficient Handling --&gt; Time &amp; Cost decrease</b>	8	TCI Provider 1, Contractor 2, 3, 4, Consultant 2, 3, 5, 7
	Better <b>site layout planning</b> and more efficient <b>space management</b> due to increased transparency and forward-looking site management approach --> citation from contractor at case study site: "Soon I'll be running out of space on the job site to put the formwork. Where shall I put the formwork?"	6	TCI provider 1, Contractor 1, 2, 3, Consultant 6, 7
	Solution is directly addressing the <b>needs of the workers</b> on site and deliver the generated value directly to the people who actually put the plan into practice (Site manager, construction worker), so construction tasks can be executed in a more efficient and secure manner, also integrating feedback from the construction site to what is planned	5	Client 1, TCI Provider 1, Contractor 1, 3, 4

D	TCI Provider		
	TCI provider benefits from a better planning from the contractor side. If the contractor knows exactly when, which TCIs are needed where on site, the provider can deliver just-in-time and benefit from a close collaboration with the generated knowledge about the TCI utilization from the construction projects	5	TCI Provider 1, Contractor 1, 3, Consultant 2, 3
	Contrast: Depending on the business model, the created value of the solution might interfere with the interests of the TCI provider as they want to maximize the amount of items, they rent out to the construction site	4	Contractor 4, Consultant 3, 6, 7
	Get more involved in the project and provide a knowledge-based and collaborative service to the contractor	2	Consultant 2, Consultant 5
	Better and forward-looking planning of the own stock yard --> Less overstock due to transparent information how many elements are needed when on which project	4	TCI Provider 1, Consultant 2, 6, 7
	If the solution is applied for calculating the formwork demands for the simple structures, the supplier could put more time of design engineers into focusing on the complex and more important formwork constellations on the project	1	TCI Provider 1
	If the solution is used from the TCI-provider: Easy calculated offer for standard and simple building structures, automatically derived from the tender documents (building model) --> First mover benefit --> Can be directly integrated into the project, taking an active role, giving advice for the design and planning as well as calculate the TCI demands	5	TCI Provider 1, Consultant 4, 5, 6, 7
	As the TCI provider can give a detailed offer based on the building model, the offer is also not only evaluated by the cost per item, but rather by the cost impact on the whole construction project --> Supplier with higher item costs, but a much better workflow and system would end up winning the contract, as the project manager has the transparency to compare different offers on a much higher level of detail (over time and impact on site)	1	Consultant 5
	Higher per unit/cost but lower total prize in bid, as a project specific TCI utilization is offered which requires less TCIs --> More competitive prize	3	Consultant 2, 3, 7
E	Productivity		
	Obvious productivity increase due to more transparency, control and lean management on site	10	TCI Provider 1, Contractor 1, 3, 4 Consultant 2, 3, 4, 5, 6, 7
F	Safety		
	Safety is generated generally as a secondary effect of a better and more transparent planning and management of TCIs	9	TCI Provider 1, Contractor 1, 3, 4, Consultant 2, 4, 5, 6, 7
	If specific safety measures are applied: (1) all items in the formwork process have to be considered, (2) add direct safety means to the specific task to raise the awareness of and increase safety (e.g. Safety-Risk-Factor with notification, assembly instructions for site workers, checklists for each task which TCIs are there/installed and what is missing)	5	TCI Provider 1, Contractor 4, Consultant 2, 3, 4
<b>2 Validation and Further Development</b>			
A	General Validation		
	Solution offers a tool for the automatic planning of standardized formwork elements (given some assumptions), and provides the construction site with a transparent, integrated and location-based TCI-utilization plan that can be used to better plan and manage the construction activities related to simple in-situ wall structures	12	All
	Solution is only addressing the use case of formwork elements and therefore only benefits construction projects with large amount of in-situ walls --> Decision to create a specialized solution for a few TCI types and products or a platform solution that can generate utilization plans for multiple TCIs from multiple data sources with the option to outsource the calculation engine to the supplier	7	TCI provider 1, Contractor 1, 4, Consultant 2, 3, 4, 5
	Challenge of site implementation --> <b>Change management</b> and controlling means are needed to ensure that the involved parties update the data model as changes in project appear and that the construction workers also follow the plan --> All changes have to be included in the data model to update the TCI utilization plan --> Passive progress monitoring requires the construction workers to actively track their work and what items they used via a mobile application --> Construction workers are used to get a big box of material and then they look what fits and apply it (as playing with a box of LEGO). If everything is planned, the workers have to follow the plan and the plan has to be easily understandable and applicable for the workers	5	TCI provider 1, Contractor 1, 2, 3, 4, Consultant 4
	Next step of prototyping would be to <b>apply</b> the solution to a construction site where the process in-situ wall construction is analysed without the use of the proposed solution and with it. --> <b>Reduce the amount of uncertainties</b> in each step of the solution implementation and involve the interests of all involved people to further develop the solution --> Need to conduct case studies on projects to <b>quantify the benefit</b> of how much improved productivity and how much more safety is realized on site with the use of the proposed solution	7	Client 1, TCI provider 1, Contractor 1, 2, 4, Consultant 3, 7
	Prototype needs to tested on site in a small <b>pilot project</b> to check its functionality and to get feedback from the workers who will use and benefit from it	6	Client 1, TCI Provider 1, Contractor 1, 2, 4, Consultant 7
	Many stakeholder are restrictive in using integrated solution as they fear that it can automate the whole process and thus, is not aligned with their <b>interests</b> --> Some individual interests of stakeholder will be broken by interlinking the data and automatically deriving information	1	Consultant 6

B	General Further Development		
	Link the logistics status from supplier with the database, to know how many items are actually currently on site and when the next ones are delivered	2	TCI Provider 1, Contractor 1
	Active tracking with IoT-Sensors would further strengthen the solution and the control of the site manager as if elements on site get lost or are used for tasks they are not supposed to be used, the elements can be tracked and the plan can be adjusted --> Active tracking with IoT-sensors would allow to actively track the items on site without the need that construction workers have to actively monitor their work	2	Consultant 2, 4
	Solution must be further developed to also <b>integrate other TCI types</b> than formwork elements --> Calculation engine can be used to calculate <b>scaffolding</b> and <b>safety barriers</b> and by that highly increase the safety consideration on site (Also important from a client perspective to have safe sites and provide transparency about the safety considerations) --> For scaffolding and other TCIs, maybe more data is needed (load considerations) which has to be integrated as well --> Cranes, ladders, supports, etc.	5	Contractor 3, 4, Consultant 2, 3, 4
	Due to the challenge of site implementation, create a collaboration loop between the project manager and site workers who are able to update each other about changes from the planned data model or changes from the construction site --> Ability to <b>flexibly change the master plan</b> with the current circumstances on the construction site	4	TCI Provider 1, Contractor 2, 3, Consultant 3
C	Data Sources & Extraction		
	Using default TCI dataset is good in the beginning of a project to get a first estimation in order to get an overview of the space and logistics requirements on site and to compare bids of potential suppliers.	3	Contractor 1, Consultant 4, 5,
	Open standard solution that works with multiple BIM software applications or open BIM standards and is not dependent on specific software applications as Revit or VICO --> Using IFC-building models and integrating more scheduling tools --> Either have a solution that uses standardized data sources (model, schedule) and parses the data from source to RFD or make the software applications automatically extract the data as Linked Data (in RDF triplets) that the individual generators of the data can publish it directly to the Linked Data project environment	7	TCI Provider 1, Contractor 1, Consultant 2, 3, 4, 5, 7
	Building elements in the model have to be modelled as they are executed on site to ensure that the calculated TCI utilization plan represents exactly the processes on the construction site --> E.g. wall sequence is already known to also calculate wall endings and location system of LBS does not cut any walls and thus manipulate the TCI calculation output	3	TCI Provider 1, Consultant 3, 4
	Quantity extraction from a building model is risky as it requires a correct model setup --> BIM models are modelled differently and the solution should be able to flexibly handle variances in the BIM model --> Either put it clearly in the ICT agreement how the model must look like or create adjustment possibilities of the solution	2	Contractor 2, Consultant 4
	Need for a <b>data-driven project delivery</b> where a data model is created to support the construction project in every step --> <b>Structured data</b> in the construction projects with data model consideration and standardization how to describe and model the data --> Using data in construction is also quite new approach and the industry has to adapt to it, in order to fully implement such solutions (Feedback from the construction site directly to the data model)	6	Contractor 2, 4, Consultant 2, 5, 6, 7
	<b>Standardized ontologies</b> and language must be established to describe the building data in its holistic context --> Standardized ontology framework for the construction industry to describe e.g. the building elements, the schedule information and the TCIs which all stakeholder can use to provide their information in a standardized way --> Provide the suppliers with a standardized language (ontologies) to describe their products and share their data. Project manager can then use this data in combination with all other datasets from the project for a holistic data integration --> Integration of different stakeholder into a project is only possible with the standardization of data --> Difficult to classify such a complex context as the built environment and its project delivery	5	Consultant 2, 3, 4, 5, 6
	<b>Data integrity</b> is a very important aspect in such an integrated and data-driven process --> <b>QA-process</b> is needed to ensure that the input data complies with the specifications --> For full functionality of the solution, it requires more standardization and digitalization in the construction industry as false data extraction would result in chaos on site as the wrong TCIs are calculated and the benefits cannot be realized --> As construction project often lack of structured and holistic data, an effort is required to adjust and modify the data (building model and schedule) before it can be used for applying the solution --> Automated rule-based checking of the quality of the data sources (in LD via SHACL) to see if the individual data model complies with the requirements --> Could develop a dashboard to report the warnings back to the modeler, so the model gets modified accordingly to ensure the quality of the data sources and the security of the correctness of the output --> Supplier who would provide their service to the data model could have a pre validation of the model to check if all the required measures and geometries are existing to generate the TCIs demand	5	Contractor 2, Consultant 3, 4, 5, 6
	<b>Quality assurance process</b> and approval process is needed to make sure the data complies to the requirements and also the right version of the data is used for providing information for the TCI utilization plan --> Only what is approved can be used for this consideration --> Need to keep control over the process of what data is used and if the data has the required quality and how the data is processed to get information that benefits the process --> Very hard to implement a totally open and interlinked solution (risk of not getting the required data quality) as long as there is no 100% clean standard	3	Consultant 3, 5, 6
	<b>Consideration of the technology level</b> of the relevant stakeholder in the industry who would interact in a data environment with this solution --> Solution depends on the input of the different stakeholder in the construction chain and thus requires a certain level of technology of all the stakeholder --> Technology level of many stakeholder in the industry might not comply with the requirements --> Enable <b>manual input</b> to the solution and answer question how much of the process can be done without BIM	7	Client 1, TCI Provider 1, Contractor 2, Consultant 2, 3, 6, 7

D	<b>Data Management</b>		
	Right approach to use an open data format as Linked Data that can disrupt the industry and improve collaboration --> Linked Data allows to establish full data integration if all stakeholder collaborate with their specific input within the open project environment where the data model is hosted --> Pushes the data generation and distribution responsibility towards the supplier and then pulls the required data to create value for the project	2	Consultant 2, 5
	Good idea to use Linked Data and integrating it in a holistic and functioning approach to the existing process of project delivery	1	Consultant 6
	Data model has to be hosted by one party which provides access to specific data for the involved stakeholders	1	Consultant 5
	Implement it in the environments the stakeholder already use --> Integrate Byggeweb into the solution for example for data extraction and publishing as the ideal current scenario in the industry	1	TCI Provider 1
	Solution can also be done with usual data integration and the use of open APIs to extract the data and would probably be easier to apply the solution in the current industry than Linked Data --> Linked data is one approach to do it and a way of working that opens up the process to different stakeholder who could add their information to the project --> Linked Data is only one possibility to use such a solution and Triplets are only a way of specifying objects, its properties and describing their relationships and still requires a lot of effort to develop a holistic ontology framework for the industry	4	Consultant 2, 3, 4, 5
	Linked Data approach provides a framework to include IoT-data into the existing solution	1	Consultant 5
E	<b>Data Processing &amp; Querying</b>		
	Create a more holistic solution that considers all aspects of planning and managing formwork elements (e.g. all items that are used, curing time for concrete, time of formwork in use, cycle plan with the work sequence to generate wall endings) --> Also include slabs, columns, beams in the formwork calculation engine	2	TCI Provider 1, Contractor 4
	Add historic information about the formwork elements, how many times the forms were already used and how many times can they still be reused before disposal	1	TCI Provider 1
	Make solution more usable for the user (e.g. Introduce some visual programming for building the rules for the calculation)	1	Consultant 3
	Challenge to automate the process of a holistic formwork calculation --> Use solution to calculate formwork elements for simple wall structures and enable a <b>manual input</b> from formwork experts for complex structures, but also for change management --> Fully automatic solution might not be able to cover all geometries and complexity of structures (If the solution solves 80% of the problem, but it takes 80% to solve the last 20% of the problem, then there is an issue for implementing the solution in real life) --> Filter options to only select the simple walls and mark the walls that have to be calculated manually	8	TCI Provider 1, Contractor 1, 2, 3, Consultant 3, 4, 5, 7
	<b>Option 1:</b> Creating a solution-integrated and more advanced TCI engine which is able to calculate the precise project demand for different TCI types with all their supplementary items (based on default TCI sets or real products) and derive a utilization plan (e.g. using advanced algorithms for a 2D-consideration of the formwork calculation) --> Solution must be able to calculate the correct demand of many different products! --> Contractor 4 also mentions that the catalogue of items will be quite big to create a holistic formwork calculation within one solution (including slabs, columns, beams in the formwork calculation engine and all other building elements for other TCI types)	4	Contractor 1, 4, Consultant 3, 7
	<b>Option 2:</b> Outsource the calculation engines towards the different stakeholder who act as consultants for their specific specialty --> TCI supplier receives the required project data and provides the demand of his products with the use of an advanced calculation engine as well as the service of planning and managing the items on the project --> Linked Data approach allows to share the required data to the stakeholders who provide their consultancy service --> e.g. A formwork design and utilization plan can be provided from PERI and the site manager can use this information for developing a lean site & logistics process that also gives feedback to and can optimize the project schedule --> Similar to an approach from TNO: BIIM BOTS - AUTONOMOUS CLOUD APPLICATIONS --> Create an open solution that can integrate as much bots as needed to the system architecture and establish an infrastructure for stakeholder integration so they would provide the project with the required input, based on their products --> No solution can do everything, so the more generic the data processing of the solution is, the better! (Focus on data integration and the holistic process flow to generate the desired benefits on site)	5	TCI Provider 1, Consultant 2, 4, 5, 6
	Create a holistic TCI planning and management tool that integrated all different types of TCIs	2	Consultant 5, Contractor 4

F	<b>Data Visualizations &amp; Distribution</b>		
	Easy accessible information for people who actually use the data in their work (dashboard for project manager and mobile application for the construction workers) and by that, solution reaches all relevant stakeholder --> From the experience of <b>Contractor 3</b> , a dashboard on a big screen on the construction site works pretty well to provide a weekly overview in regular meetings (as in LPS) --> Also: mobile application for workers is already in use and can be used to inform/remind the worker directly on the TCI requirements for each task	11	<b>Client 1, TCI Provider 1, Contractor 1, 2, 3, Consultant 2, 3, 4, 5, 6, 7</b>
	Good to tailor-make the visualizations and data distribution to the stakeholder it is targeting --> PMs demand automated dashboards to control the construction site and receive updated information from the workers	3	<b>Contractor 1, 2, 4</b>
	As data is already there, individual dashboards can be developed for different stakeholders which different interests and focus areas	1	<b>Consultant 5</b>
	Great that the solution only works as a data model and doesn't draw elements into Revit as it is not needed and would only overcomplicate the 3D-model	1	<b>Consultant 5</b>
	Visualize the generated data in a plan or building model that shows the specific items. Further integrate the solution into a digital construction site planning (4D) that allows the worker to review the digital twin and also allows a safety professional to analyse the process digitally and thus, prevent accidents --> Modelling the TCIs and hand out shop-drawings for the construction workers (as IKEA instructions) would help the workers to get an overview of what is needed where and how to install it --> Auto-generated shop drawings	4	<b>Contractor 1, Consultant 5, 6, 7</b>
	Benefit of the solution has to be made visual clearly understandable to be implemented in the conservative industry. --> Comparison between how much time they spend on a conventional project for handling formwork and how much they could save with the proposed solution (in terms of time, resources and money)	2	<b>TCI Provider 1, Contractor 2</b>
	Add assembly instructions for each task in the mobile app in order to raise the awareness for safety and allow the construction workers to follow the instructions for a safe installation and dismantling of the TCIs for each task	2	<b>TCI Provider 1, Contractor 4</b>
	In the mobile application, add that the workers receive a checklist of what task are planned today and the next day including TCI quantities and where the TCIs are currently supposed to be located	1	<b>Contractor 1</b>
	Use the dashboard on a screen in a construction container on site to provide a good overview of the TCI utilization for the construction teams and the foreman to plan the upcoming days --> Limit the data to what is actually needed from the foreman (Gantt diagram with task information, location information and TCI quantities per task)	2	<b>Contractor 1, 4</b>
	Safety Risk Factor can be highlighted in each task in green, yellow and red, identifying the risk level of the task regarding the utilization of the TCIs	1	<b>Contractor 4</b>
	Further development could be to include an XML output for directly communicating with an ordering system of a supplier --> Click on app to automatically request TCIs	1	<b>Consultant 3</b>
	Use augmented reality to compare what is planned to what is installed --> E.g. AR at PERI or Pascal --> Combination of AR and the automated planning of the presented solution could be very interesting --> According to <b>Contractor 4</b> , image recognition could also check if what is planned is actually executed on site	2	<b>Contractor 4, Consultant 7</b>
G	<b>Active Tracking with IoT-Sensors</b>		
	Active TCI tracking should be the next step to even more increase the transparency and control over the TCI management with real time data from the construction site --> Quite easy implementation as the solution is cheap, easy to use and cloud based --> Not only knowledge where the forms are supposed to be, but where they are actually located --> Would provide the construction project with automatic feedback and control over the workflow with real-time information of what is where to compare planned vs. reality --> Would also allow to better integrate the solution to the site planning and management (Real time site logistics with location consideration by using IoT-sensors) --> Active tracking would reduce the responsibility of the workers to track their work manually --> Less risk of human failure --> Would definitely improve the reliability and functionality of the solution especially with items that are reused on site multiple times as formwork (e.g. If a dynamic stock with just-in time delivery is chosen and then the workers cannot find the items and there are not enough spare items on site, you are really doomed) --> Active tracking would reduce the risk of workers not following the plan	7	<b>Contractor 1, 3, Consultant 2, 3, 4, 5, 6</b>
	- Instead of IoT-sensors, which send location information of the items to the database, the TCIs can be equipped with QR codes, which a foreman can scan --> Information of where the scanned item is will be directly communicated with e.g. the crane who then knows where to get the item from and where to move it next --> Transparent information due to active TCI tracking through workers reporting their activities --> Would create knowledge where the items are, where they have to be moved, when they are installed and when they are ready for dismantling --> Requires an active role of the construction worker, tracking the construction workflow --> change management --> However, is seen more efficient and better than using location-based IoT-sensors, as the workers can add much more information in their reporting than only the location (e.g. issues, delay, damage, etc.)	1	<b>Contractor 4</b>
	Workers should also get insights and benefit from the active tracking, e.g. if a item is not where it is supposed to be, the worker can locate an item of the same type which is located nearby	1	<b>Consultant 6</b>
	Recognizing items and their location with image recognition might be better as the technology is emerging super fast --> Recognize the size and type of the items on site --> how many items are used/ on site	2	<b>Contractor 4, Consultant 3</b>
	Sensors (if integrated robustly in the elements) can also have much more benefits as they would count the use of a form and how many times it can still be reused before disposal	1	<b>Contractor 1</b>
	Difficult to install a sensor that withstands this, high risk of breaking the sensors during construction --> Would be too much of an effort and not beneficial for a formwork supplier to apply IoT-Sensors to all items (for some preassembled parts, it is already implemented) --> Sensors would need to be on every item to ensure usability of the tracking system. Not feasible right now and no company currently does that	1	<b>TCI Provider 1</b>
	Workers might not want to be tracked? --> Need to see the benefit in a more transparent and better workflow to actually utilize the solution	1	<b>Consultant 6</b>

H	Scalability of solution for other TCIs		
	Open system of the solution can be applied and scaled to many different TCIs which have a relation with what is modelled and therefore can be quantified by a rule-based calculation engine --> Generic and data-driven approach of linking TCIs to existing BIM data can be applied to several areas --> General problem of all TCIs is the lack of information regarding their utilization	11	Client 1, TCI Provider 1, Contractor 1, 2, 4, Consultant 2, 3, 4, 5, 6, 7
	Each TCI type requires an individual ruleset to calculate its demand for the project --> Where to get the data from, what parameters are required, etc. --> Furthermore, a system has to be established that applies a tailor-made calculation method to the different products within each TCI type group.	2	Consultant 3, 5
	Calculation engine can be used to calculate <b>scaffolding</b> and <b>safety barriers</b> and by that highly increase the safety consideration on site (Also important from a client perspective to have safe sites and provide transparency about the safety considerations) --> For scaffolding and other TCIs, maybe more data is needed (load considerations) which has to be integrated as well	5	Contractor 3, Consultant 2, 3, 4, 6
	Solution can also be applied to precast industry for planning and calculating the demand of PushPullProps (supporting the precast elements until they are self-sustaining) --> Big market in Denmark for precast concrete and need to plan the TCIs in this industry!	2	TCI Provider 1, Consultant 6
	Option 2 of the suggested further development consists of a generic platform solution with a Linked Data environment to which all kind of service provider in the construction project could integrate the demand of their products for the given project specifications	2	Consultant 4, 5
	Machines (e.g. cranes) and other TCIs which cannot directly be linked to the building model are more related to where it is located and how far it can reach --> Can be integrated in the next step of site logistics planning	1	Consultant 6
	Get feedback from construction workers about which TCIs should be implemented in the solution --> Depends which items cause the most difficulties and where the workers are convinced that the solution will add value	3	Contractor 1, 2, 3
I	Integration to Site Planning & Management		
	Integrate the created knowledge and transparency of the TCI utilization to site planning in order to optimize the site layout and logistics and enable a lean management --> Solution is only providing the raw data of how much is needed where, but doesn't suggest, for example, where it has to be stored before and after use --> Digital integration into a site & logistics optimization tool --> Generating a data driven site & logistics plan for the construction site which takes into account different aspects as the quantities, location, geometry, logistics and space requirements of TCIs, PCIs as well as the construction workers	5	Contractor 4, Consultant 2, 3, 4, 5
	Active tracking of the TCIs via IoT-sensors would further foster the integration of the solution to the site management --> Where do you store it and check how does it move --> Controlling unit for active site monitoring to check compliance with the plan --> This can be done with location-sending sensors, QR-codes or also a camera which is identifying the TCI types and location on site	3	Contractor 4, Consultant 3, 5
	Location based integration of construction elements is the key for enabling a more efficient site management	5	Contractor 1, 3, 4, Consultant 3, 4
	Write back TCI utilization data to schedule and model and try out different scenarios of the model or schedule (e.g. with AI) for improving the project delivery (e.g. avoid special formwork elements, reduce amount of formwork sizes, adjust schedule according to TCI information (requirements, availability, etc.)) --> Optimization of model, schedule and site logistics based on the calculated TCI information --> Full integration in the construction process (Where is the stock, how are the items moved from one part of the construction site to another part, which items are used/ available right now, where to store the items after use to ease the distribution to the next installation location)	3	Consultant 2, 4, 5
	Consider a packaging service from the TCI supplier or Site manager --> With the information of what items are required where on site, a responsible party could set up and locate all the items which are needed for each construction activity on the location, where they are needed --> Would allow a lean management with an efficient space utilization and construction flow on site and reduced waste in terms of material, time and space	1	Consultant 4



3 Business Model			
A	Integration in Existing Project Delivery (current industry)		
	Linked Data approach in solution requires a lot of effort in terms of standardization, QA of the used project data and a general increase of the level of technology and an open mindset regarding new technologies of all stakeholder in the industry --> Limitations in the current industry have to be considered in the solution and thus, some modifications are required to implement it in the current industry	1	Contractor 1
	<b>General contractor</b> with a Design&Build contract could implement the solution by setting up a ICT agreement which requires project parties (architect, engineers and sub-contractors) to establish a more open data environment and comply with the specifications in the ICT agreement --> As they have the whole value chain under them, they are able to control the data flows and easily implement such a solution --> Contractor benefits the most of implementing the solution as it will give him control and transparency over the site layout and workflows --> If contractor is not involved from the beginning, it is difficult to demand a certain data integrity and thus, the solution is difficult to be realized --> <b>Client</b> cannot drive the use of such a solution as they do not have enough impact on the value chain (could require such a solution and then shift the responsibility for implementation towards the contractor or a consultancy) --> <b>TCI provider</b> do not have a contractual relationship with the data provider and therefore would rely on something they cannot guarantee	5	Contractor 1, 3, 4, Consultant 4, 6
	For the implementation of the solution for a <b>contractor</b> , a consultant could be involved who is introducing the solution in a pilot project, from which onwards, the contractor will gradually get familiar with the solution and incorporate it in their processes --> Small contractors would use the solution as a consultancy service	5	TCI Provider 1, Contractor 1, 4, Consultant 2, 4
	Providing a software is not sufficient as there is always a need to accompany the software with a consultancy service (at least in the beginning)	3	TCI Provider 1, Consultant 2, 3
	Could be an <b>additional service</b> of the site & logistics management with a data-driven approach to optimize the site logistics management either, offered by an external company as Ajos etc. or directly from the contractor	2	Consultant 2, 6
	A modified solution approach with usual data integration and the use of <b>open APIs</b> to extract the data will be implemented easier in the current settings of the industry --> Would still require a standardization of the APIs, but this approach is more likely to be realized in contrast to Linked Data	3	Consultant 2, 3, 4
	System architecture of the proposed solution with data extraction from the different authoring tools in a project is needed now, as the Linked Data approach is not yet implemented in the industry	1	Consultant 5
	Consultancy as a service can be offered by the specialized TCI provider who are consulting the contractor with the utilization of their specific product --> Need to gain access to the data model from the general contractor or a client consultancy --> Would provide a competitive advantage for the TCI provider	1	Consultant 6
	Consultancy service is required, that sets up the linked data platform for each project and either develops the calculation engines for the TCIs in the project or helps the TCI provider to develop their own calculation engine to share their data with the project platform.	1	Consultant 4
	Be aware of the impact of the solution to the different stakeholder and their specific interests --> Might require new roles or make existing roles obsolete	2	Consultant 6, 7
B	New Project Delivery System (Linked Data vision) --> See option 2 in category 2E		
	Linked Data project delivery vision where all stakeholders generate and own their data, but provide it to the linked project environment where it is integrated into the data model --> Decentralized nature of the project delivery will be the future when the focus will go more towards the data model and not the software solution --> Different stakeholder would provide their information as consultancy-as-a-service for a specific part of the project	3	Consultant 2, 4, 5
	New roles and responsibilities will arise in the market and we need to go in this direction of getting better data --> Role of generating the project data model, hosting it centrally, providing access to specific data and integrating new data to the model will gain more and more importance	4	Contractor 2, Consultant 2, 5, 6
	One party is centrally hosting the data model from the beginning of the project and providing and integrating data from the different parties involved in the project as the project evolves --> Question of who will be responsible for hosting the data needs to be decided project specifically --> In the construction phase, the responsibility could go to the general contractor	2	Consultant 4, 5
	Make the BIM authoring tools automatically extract the data as Linked Data (in RDF triplets) to directly communicate with the data store of the data model --> individual generators of the data can publish it directly to the Linked Data project environment	1	Consultant 5
	In the construction phase, the contractor is gaining most access to the model in order to plan the site and logistics and have more control over construction flow	2	Consultant 4, 5
	Supplier and sub-contractor gain access to the specific data, they need to calculate the demand of their product/ service and integrate it to the data model and the existing site workflow --> Will act as a service provider for the project and includes his expertise and input to optimize the model, schedule and site management regarding costs of TCIs (especially handling) and the production flow on site	3	Consultant 4, 5, 6
	Scenario is realistic as all the data is there and also smaller companies will be able to publish their project input or at least provide the raw data for the engineer to translate it into the Linked Data format --> Industry is aiming towards this scenario --> Requires a change in the mindset of the people to work in an open project environment --> Requires a standardization process in the whole industry to develop the required ontologies	5	Contractor 3, Consultant 2, 4, 5, 6