Flexible Processes and Improved Technologies for Urban Infrastructure Construction Sites

Reporting

Project Information

PANTURA
Grant agreement ID: 265172

Funded under
FP7-ENVIRONMENT

Overall budget
€ 4 682 605.38

EU contribution
€ 3 244 452

Closed project

Start date
1 January 2011

End date
31 December 2013

Coordinated by
CHALMERS TEKNISKA HOEGSKOLA AB
Sweden

This project is featured in...

RESEARCH*EU MAGAZINE
Preparing for the advent of smart cities

NO. 23, JUNE 2013
Final Report Summary - PANTURA (Flexible Processes and Improved Technologies for Urban Infrastructure Construction Sites)

Executive Summary:
The performance of the road and railway network is largely dependent on the state of the critical transport infrastructure such as bridges. Today, bridge owners and managers are dealing with a large number of structurally deficient, obsolete bridges and construction and maintenance activities are a frequent cause of the major negative impact to both users’ convenience and welfare.
Eleven internationally recognised sustainability indicators were selected and used as the backbone of addressing low-disturbance construction.
To address not only financial criteria, a proactive process strategy, performance-based procurement and life cycle systems engineering approach were proposed. This strategy deals with risk management at different stages of the urban project and stimulates and facilitates the balanced involvement of all actors and stakeholders at all stages of a construction project.
To address the problems in a complex urban construction situation, with its numerous stakeholders and conflicting interests, the theory of multi-criteria decision analyses was proposed. This project shows, by three case studies, how it can be used in order to provide support to the decision makers.
In order to speed up the gaining of a broad-based consensus among the stakeholders, an information and communication technology (ICT) instrument was proposed. The proposed ICT instrument is an integrated solution between structural (BIM) and geographical (GIS) data, which provides a powerful assessment tool for decision makers.
New challenges call for new techniques. Therefore, innovative and effective bridge strengthening and upgrading techniques were proposed, as well as new methods and technologies, which provide alternative, innovative and effective methods for new construction and renewal of bridges, including: logistics optimization, storage space rationalisation or technological worker safety enhancement.
Design recommendations for fibre reinforced polymer-steel composite bridges were developed. An innovative pre-stressing technique using fibre-reinforced laminate without needs for any anchorage systems was developed and applied on a concrete bridge in Sweden.
To conclude, the ambitious over-all objective: low-disturbance construction has been achieved by approaching the problem from an interdisciplinary perspective. The main results include: proactive procurement process, multi-criteria indicators and decision analysis, an integrated ICT decision instrument, and innovative and fast bridge construction, strengthening and upgrading techniques.

Project Context and Objectives:
The road and railway transport network forms the backbone of European transportation systems, accounting for more than 80% of passenger transport and 50% of goods transport in Europe. In the technical platform for European construction (ECTP, 2012) it is stated that Europe possesses one of the densest and most developed infrastructure networks in the world, a huge legacy and accumulated investment inherited from its long history. Most infrastructures that were constructed in the period 1945-1970 were designed for a working life of 50 years. Now these infrastructure networks are often strained far beyond their intended capacities in terms of traffic flows and traffic loads. Furthermore, climate change may also have altered the climatic conditions considered at the design stage. Consequently, many of the
existing infrastructures no longer fulfil the current functional requirements and today’s safety and quality standards no longer form a resilient foundation for Europe’s economies.

A large number of bridges are located in densely populated urban areas and serve as a vital part of the infrastructure in all European cities. Moreover, the bridge stock has a very high asset value as capital to be protected. Bridges in cities are often key objects and landmarks of the urban architecture. Today, bridge owners and managers are dealing with a large number of structurally deficient, obsolete bridges. To date, construction and maintenance activities relating to bridges are a frequent cause of the major negative impact in densely populated urban areas with regard to both users’ convenience (such as service disturbances, disruptions, accessibility problems, delays, traffic jams and a distorted urban landscape) and welfare (such as obstacles to safety and security, nuisance from noise, vibration, dust, and air pollution).

In addition to disturbance and disruption, another main challenge for urban construction processes, including bridge (re)construction projects, is the inefficient use of resources, i.e. materials, energy, equipment and labour related to construction. Construction processes for bridges in densely populated urban areas with a zero negative impact and with the most efficient use of resources requires an integrated strategy. It is evident that, throughout its lifecycle, a bridge project is of key importance and has a significant impact on every city. As a result, the PANTURA research project focus on developing and implementing innovative solutions for the design, engineering and co-ordination of new construction and the renovation of bridges in populated urban areas.

The main aim of PANTURA was to realise a radical breakthrough by equipping the authorities, stakeholders and experts with a comprehensive instrument (methods, tools and techniques) to prepare and perform bridge construction, maintenance, repair and renovation processes in the most effective and efficient way, in the shortest possible time, with the most efficient, sustainable use of resources and with zero disturbance and disruption for the urban environment and urban life of the inhabitants. PANTURA aimed to improve highly flexible off-site production and construction processes, while significantly reducing labour-, machine- and cost-intensive on-site activities in order to achieve the optimal performance with the most efficient use of resources and zero carbon emissions. To co-ordinate these processes in the most effective way, PANTURA aimed to develop and use a proactive co-ordination strategy and integrated ICT tools in order to anticipate and prevent any disturbance in the areas surrounding the construction site and the city. These novel approaches and solutions were validated through real case studies.

Within this overall aim, there were a number of specific sub-objectives that relate to change management, construction process management, new design concepts for new and existing bridges, improved logistics for proposed technologies of various innovative strengthening techniques and industrial construction. PANTURA also focused on improving and developing effective processes related to the construction of new bridges, as well as the maintenance, repair and upgrading of existing bridges. The objectives of PANTURA were:

1. To generate an integrated method for preparing, performing and managing flexible construction processes, and to
   a) achieve the most efficient with zero carbon emissions construction sites, as well as zero disturbance in
the surrounding areas and the city, by developing and deploying a proactive, flexible strategy based on
intelligent forecasting and monitoring
b) optimise the efficiency of the design, production, construction and maintenance of European bridges
using an advanced systems engineering method for the infrastructure network
c) shorten significantly the construction time and extend the sustainable performance of bridges through
integrated procurement and asset management

2. To develop an interactive tool for monitoring, planning and co-ordinating complex urban projects, and to
a) achieve the optimal co-ordination of urban projects using an urban logistics management system based
on meta-information modelling
b) increase the transparency, effectiveness and speed of communication between governmental bodies,
construction players, businesses and citizens through an open-source semantic web

3. To enhance the technology for designing and constructing new bridges in densely populated urban
areas, and to
a) propose new methods and technologies that provide alternative, effective methods for the new
construction and renewal of bridges in densely populated urban environments
b) develop new types of industrially built bridge suitable for the urban environment for swift, easy assembly
c) validate the comprehensive instrument (methods, tools and techniques) through real case studies

4. To enhance the technology for maintaining and refurbishing existing bridges in densely populated urban
areas, and to
a) establish effective bridge strengthening and upgrading techniques
b) develop and implement new and automated strengthening and repair techniques using various types of
composite material
c) develop innovative pre-stressing techniques using fibre-reinforced laminate (FRP) with the rapid curing
of epoxy in order significantly to reduce the time needed for strengthening and repair work

5. To analyse and benchmark best practices and extend measures and standards relating to the lifecycle
sustainability of urban projects, and to
a) compile and perform a comparative analysis of best practices and to benchmark the results of
PANTURA against the best practice and sustainability standards
b) propose new measures and standards for sustainable, healthy, safe construction sites in urban areas
c) contribute to standardisation in the fields of structural reliability and safety of infrastructures and open
ICT standards

6. To empower the (local) authorities, stakeholders and experts through an awareness of the real
breakthrough by deploying the innovative strategy, tools, technologies and measures in urban projects,
and to
a) enable the professional decision-makers, planners, construction managers, field engineers and
technical experts who are actively involved in urban infrastructure projects and disseminate the new
knowledge in a number of European cities
b) establish a stakeholders’ panel consisting of local authorities and key construction players across
Europe that will outline an implementation roadmap
The PANTURA project was structured in five RTD work packages; one work package (WP7) related to organisation of the stakeholders’ panel, training, dissemination and exploitation and one Project Management work package (WP1). All the work packages had clear interconnections and lean interdependence on one another. The composition of activities and types of partner involved in each work package has ensured the cohesiveness of research and development within and beyond the work package.

Two case studies (new bridge in La Palma, on Canary Island and refurbishment of existing bridge, the Koninginne Bridge in Rotterdam) were promised from the beginning of the project as they were regarded as very important to the PANTURA project; i) as indicators for current practice related to all parts of project (defined by all the WPs), ii) as input to the Stakeholders panel and iii) as a way of measuring progress and achievements in PANTURA in relationship to processes and techniques used in the practical infrastructure projects. However, during the project additional bridges were added as limited cases in order to fulfil certain tasks and research objectives.

All the results are produced in twelve RTD deliverables within five RTD work packages. Within Project Management (WP1), two summarising RTD deliverables are produced; one as mid-term Monitoring and evaluation report (D1.6) and Summary of the final results (D1.14). Stakeholders’ panel, training, dissemination and exploitation are summarised in four deliverables.

The PANTURA project is shared and disseminated via the following media:
1. The PANTURA homepage contains general information on the project and is accessible for the public. ([www.pantura-project.eu](http://www.pantura-project.eu))
2. The Share point is used for saving documents such as agendas, minutes of meetings, calendar for coming events, final reports and official documents. The Share point is a confidential website for the participants of PANTURA only, as well as the project officer and evaluator assigned by the commission.
3. The PANTURA newsletter is a short yearly document for handing out (printed or digital as a pdf) describing the general concept and progress of PANTURA to stakeholders and practitioners within EU.
4. Presentations at a number of conferences, workshops and meetings.
5. Papers in scientific journals and other media.
6. Interaction with public authorities, consulting companies, other stakeholders and media representatives

Seven consortium physical meetings were organized. Three of them were combined with stakeholders’ panel meetings and disseminations activities. Apart from that, there were some working meetings and regular TSC meetings (once a month).

Project Results:
The main S&T results obtained during three years’ duration of PANTURA project are summarised in twelve RTD deliverables within five RTD work packages. First the results from each deliverables will be presented by starting with the sustainability indicators, continuing with management issues and finishing on the design and technical achievements. Finally, the fulfilments of the DoW will be addressed and general recommendation when appropriate will be made.
Comparative analysis of best practices, benchmarking and selection of suitable indicators

Research in PANTURA started by thoroughly analysing the best practices in sustainable urban infrastructure projects as a part of the work in Work Package WP 6 (Benchmarking and measures). The first study (Comparative analysis of best practices, D6.4) covered adapting a benchmarking in order to develop an indicator suite that provided a tool to communicate the following aspects of an urban construction project throughout its lifecycle:

- Promotion of efficient and sustainable resource use,
- Minimization of disturbance/disruption for the urban life of inhabitants,
- Minimization of disturbance/disruption for urban environment, and finally
- Reduction of lifecycle costs associated with urban construction.

Parallel with the first study, research in WP 2 (Construction processes) and WP3 (Tools for monitoring, planning coordination) started by consolidating the body of knowledge on advanced methods and tools for planning, communication and the co-ordination of construction processes on different scale levels, from the construction site and the surrounding areas to the city (D3.17). Also at the beginning of the project, research in WP4 (Flexible construction techniques for new bridges) and in WP5 (Flexible construction techniques for maintenance and refurbishment of existing bridges) started with both case study bridges and overview of suitable existing technologies. The needs for maintenance and refurbishment of bridges in urban environments (D5.3) started in order to identify general view of the condition of European bridges and what bridge authorities and owners have as their priorities when dealing with this part of road and railway networks.

The indicator selection and development of the evaluation process (Comparative analysis of best practices, D6.4) were performed in accordance with a framework derived from the UN framework for the development of sustainability indicators. This process involved the initial determination of relevant indicators followed by an analysis of data availability.

To determine relevance, an extensive literature review was conducted of existing indicator sets and sustainability rating systems used for similar projects. Ultimately, sixteen internationally recognized indicators were selected and a profile developed for each of these. The candidate indicators were sent for review to a panel of international experts and stakeholders. The results of the survey were analysed in a transparent and consistent fashion, and the following indicators were selected for use:

- Worker safety during construction
- Safety of residents
- Noise
- Mobility
- Total time of construction on site
- Reused or recycled materials
- Emission of greenhouse gases
- Generation of waste
- Total use of materials
- Life cycle costs
- Dust emissions
In many cases, the analysed survey data yielded information that supported commonly held beliefs. The PANTURA indicator set thus, suggested that if an urban construction project does not contribute to additional accidents, does not produce more construction waste, does not lead to an increase in dust, and is completed within an appropriate time frame then the inhabitants are likely to perceive less disturbance.

Data availability was evaluated through a comparative analysis of eleven existing projects. These projects provided introductory information with regards to data availability, prior to the benchmarking phase that starts in year two. Findings from this phase provided information regarding project documentation requirements and issues associated with the implementation of this methodology. All of the indicators selected in the PANTURA suite had relevant data available; however, in many cases the available data was not in the correct format for immediate use in the indicators. However, future work was necessary in the field to optimize the indicators so that they can be implementable with the available data.

The following criteria were addressed with the respective indicators:

- **Use of resources**
  - Indicator: total use of materials, reused or recycled materials, LCC, generation of waste
  - Indicator: Carbon footprint
- **Carbon footprint**
- **Adaptability to climate change:**
  - Indicator: GHG emissions (including carbon footprint)
- **Risk assessment**
  - Indicator: Safety of residents, safety during construction of workers, dust emissions, noise emissions
- **Performance criteria**
  - Indicator: Noise emissions, dust emissions

The development and weighting of a PANTURA indicator suite provided a starting point for assessing existing projects. As illustrated in Table 10 (D6.4) the proposed indicator suite was evaluated using 10 existing projects. Appendix D provides a complete overview of the range of the construction materials and technologies used. Both new bridges and rehabilitation of bridges were covered.

With regards to material use, the case studies covered a wide range materials including:

- Concrete
- Steel
- Timber
- Composite (concrete and steel)
- Fibre reinforced polymer

The state of the art new bridge solutions which were benchmarked (D6.9): steel bridges, timber bridges, and variations of in-situ concrete bridges. The state of the art rehabilitation procedures which were benchmarked were: deck enforcement by welding, deck and foundation replacement, in-situ cast concrete beam, FRP beams, and precast concrete beams.

The sustainability criteria through which these construction practices were evaluated were the ones developed in D6.4. This benchmarking was performed to answer the question: "which construction solution(s) are most optimal for low-disturbance sustainable construction based on the actual practice?"

This task was accomplished by benchmarking 20 actual European bridge construction projects where state of the art construction methods were used. A survey was developed based on the indicator suite to
be answered by construction managers with regards to which sustainability criteria they actively planned for. Doing so provided an idea of which aspects of sustainability were most engrained in the construction process, and where any gaps may be located. The results indicated that certain aspects of sustainability are currently everyday practice in bridge construction while others lag behind. It was however difficult to provide conclusive evidence that one bridge construction/rehabilitation methodology was significantly more attentive to low disturbance sustainable construction than others. However, what was noticed was that in the planning phase most construction/rehabilitation projects are approached in a similar fashion. Whereby the most detailed construction management plans are the ones dedicated to onsite safety. Ultimately it proved difficult to reach a definitive answer with regards to which construction methodology provides the most sustainable bridge construction with the least disturbance. This was primarily due to the fact that each individual project benchmarked was so unique that it is likely that the individual methodology results were affected by this. However, what were strikingly clear from the analysis was which elements of sustainable construction are in practice currently, and which ones need to be addressed. Another interesting aspect of these findings was the similarity between the answers for both the rehabilitation and new bridge processes. These results indicate that sustainability and low disturbance might not be accomplished through specific technologies, rather these issues as a whole need to be embraced (and incentivized). The two elements of sustainability most embraced were worker safety and recycling; Safety regulations are mandated while recycling provides a monetary incentive. These findings suggest that it is difficult to introduce materials and methods that will produce sustainable low disturbance construction and rehabilitation. Rather, what were needed are incentives (such as those for safety and recycling) which promote sustainable low disturbance construction. In addition to this, it was also found that LCAs of the various bridge solutions were infrequently conducted during the design stage of the bridge project. One of the primary contributors to emissions over the lifecycle of the bridge is the material selected for use to construct the bridge. Environmental tools such as LCA must be applied when selecting the bridge type if the environmental impact of the bridge is of importance. Future work within this work package will focus on developing standards for the aspects of sustainability and disturbance which lag furthest behind as well as the development of a multi criteria decision analysis tool which can aid decision makers in selecting (and incentivizing) sustainable low disturbance construction alternatives.

Deliverable (6.9) fulfils the objective 5b of PANTURA and all the requirements stated in DoW.

Construction processes

The results to be presented from Work Package 2 (WP2) fulfil the objectives 1a-1c of PANTURA. A systems engineering approach (D2.10) one research part of WP 2, a detailed insight into the stakeholders’ roles and requirements, plus a methodology which structures these requirements together with the sustainability criteria into a reference basis to build new process methods and tools accordingly is proposed. The development and realisation of urban infrastructural projects such as bridges is getting increasingly more difficult and complex to manage. The challenge for the actors to develop an effective solution for the project within the traditional dimensions of time, budget and quality is still very present. But society also calls for more sustainable solutions which minimizes an eventual negative impact on the environment and takes into account the interests of stakeholders. The success of a construction project ultimately depends on whether the project has remained well within the acceptance levels of the
stakeholders, especially those living in the vicinity of the construction site, and whether this situation has been the case at all stages of the Life Cycle. In an increasingly conscious and well informed environment, many parties of interest, backed by legal procedures and successful liability cases find their way to the negotiation table in order to have the undesired effects of a construction project on the agenda and dealt with in a satisfying way.

The general goal of WP2 (D2.10) was to propose a framework which stimulates and facilitates the balanced involvement of all actors and stakeholders at all stages of a construction project. D2.10 aimed at using standard methods when available to develop the Systems Engineering Framework, contributing as such to a further strengthening of the common European methodology in that field.

The introduction of national and EU regulated procurement methods such as the Most Economically Advantageous Tenders (MEAT), has opened the way towards a more active and balanced involvement of actors and stakeholders in the development and realisation of urban construction projects. In this new environment, the client, consultant, contractor and stakeholders strive to work together in order to realise a sustainable solution. Compared with many other industries, the realisation of a construction project is subject to more risks due to the unique features of its activities, such as: unique functional characteristics, geographic location, and absence of industrialized production facility, lengthy development and realisation period, complicated and dynamic construction activities, interferences from opposing parties of interests to name a few aspects. Managing those project risks are meant to control and minimize time delays, costs overruns, functional failures, hazardous situations and negative environmental impacts.

The specifics of this system engineering method were found in the management of the project requirements. The incremental process of further detailing of the requirements and the process of associating verification and validation criteria to the requirements, is fed with input results from the analysis of environmental aspects and stakeholders involvement, starting from the definition of the project goals and objectives down the Life Cycle line to the level of the contract requirements, and further to the level of basis of design and work methods.

The method has shown to have the aptitude to encompass all the PANTURA work package activities and indicate at which stage of the Life Cycle each of the work package is most effective when it comes to achieving a sustainable and urban friendly solution. While WP2 and WP3 steers the systems engineering methodology, WP4 and WP5 proposes technical solutions to be embedded in the requirements specification either explicitly or in a generic form. The systems engineering method show true flexibility with the WP6 indicators as they can be set in the concept phase as a most effective global project objective. Indicators can also be a subset of the procurement awarding criteria or the requirements specification set in the contract.

This deliverable (D2.10) fulfils the objective 1b of PANTURA and all the requirements stated in DoW. The inter-relationships between the multi-level requirements were established; the performance of the end product based on these requirements was validated and presented in Chapter 3. Scope and interface with WP4 and WP5 were defined. Description of the Critical Success Factors for an Urban Infrastructural Construction Project for measuring the success of the Project from the stakeholder’s viewpoint was produced in Chapter 2.3.
Methodologies were described for:
• verification and validation to guarantee that requirements will be met during Life Cycle in Chapter 5.2.
• risk management for decision making and process control in Chapter 4
• standardized tools such as Multi-actor and Multi-Criteria analysis (MAMCA) and CASH FLOW models, for example, can be used for completing a total package of system requirements, in Chapters 3 and 7.
• proposal for structuring tender documents for performance based sustainable procurement in Chapter 8
• organizational model which serves as a common and transparent framework for information, communication and process control between stakeholders in Chapter 6.1
• project management system framework for the progress report, validation and payment schedule in Chapter 7.3.

The aim of the Performance-based procurement method for urban infrastructures (D2.11) was to encourage the transition to a more competitive, innovative and creative construction industry. However, to date, the broader application of procurement methods of this kind by many public and private clients across Europe still faces many challenges. This deliverable aimed to introduce a method of performance-based procurement, based on the Most Economically Advantageous Tender (MEAT), for low-disturbance bridge construction projects in urban environment. The deliverable also presented a roadmap on how to prepare, organise and validate the procurement process (selection, tendering and contracting processes) of urban infrastructure projects based on performance based requirements, instead of solely deciding on lowest price bidder.

The first part of this deliverable, reviews of the key performance indicators (KPIs) of low-disturbance construction and the procurement procedure based on the MEAT principles were made. The second part reflected on two actual bridge projects (the Rotebro bridge in Sweden and the Arno River bridge in Italy) as observatory case studies to analyse how clients and contractors can implement the KPIs in MEAT. Furthermore, a workshop with the stakeholders was held to verify the methodology. Reflections on the Koninginne Bridge and the proposed approach were made. Finally, a road-map of the transition from a traditional scheme to a performance-based one was proposed.

The research team investigated the usefulness to introduce a set of objective KPIs for this purpose in the MEAT phase. It was shown that the MEAT can be implemented in combination with either the traditional (design–bid–build) or integrated (design-and-build) procurement. Special attention should be given when setting-up the MEAT protocols, particularly regarding the way MEAT criteria are defined, the decision on the priorities and the associated weighing factors, and the deployment of the most appropriate evaluation method. Over-simplifying or over-complicating the MEAT protocols can have a negative effect for the project delivery strategy, and can lead to a disputable tender result that compromises the performance achievement. The results also showed where the PANTURA KPIs could be introduced in the appointment process as well as the proposed selection approach. The implementation of MEAT to achieve low disturbance construction projects is considerably new and still requires an empirical validation. A further elaboration of the procurement strategy within the EU regulatory framework is strongly recommended in order to assure the broader impacts of sustainable construction. This deliverable (D2.11) fulfils the objective 1c of PANTURA and all the requirements stated in DoW.

The results of D2.10 and D2.11 were necessary prerequisites for the successful application of the results
presented in D2.16. D2.16 provides the framework as well as presents the PANTURA proactive strategy.

The ultimate goal of the PANTURA project was to “improve highly flexible off-site production processes, create resource-efficient construction sites, improve technologies and tools for bridge construction in densely populated areas and enhance communication between local authorities and construction companies.” In the context of PANTURA (D2.16) this implies that in order to fulfil the overall aim of the research project to equip the authorities, stakeholders and experts with a comprehensive instrument (methods, tools and techniques) to prepare and perform bridge construction, maintenance, repair and renovation processes in the most effective and efficient way, in the shortest possible time, with the most efficient, sustainable use of resources and with zero disturbance and disruption for the urban environment and urban life of the inhabitants, a multifaceted approach must be undertaken. This approach must integrate people, process and technologies; three main pillars for the proposed PANTURA proactive construction process strategy.

Changes and unexpected hurdles are everyday matter in any project, and yet, they cause stress and conflicts. Collaborative working is generally accepted to be the way to follow, including close work with legislation groups to prevent project delay. Generally, a collaborative design process is a combination of constituents: early involvement, focus on value, measurement of performance and long-term relationships. Within a working collaborative design team open communication is paramount to a successful project. Effective implementation of the proposed PANTURA Framework, based on Integrated Design and Delivery Solutions, results in integrated work processes for each phase of the project, and throughout the full lifecycle of the project. Prior to construction the team completes: 1) integrated planning (rather than specialist priorities throughout); 2) integrated design; and 3) integrated supply chains. A set of technologies and capabilities for collaboration and automation are essential for project teams to implement the integrated work processes. These include: modelling of design intent, multi-disciplinary performance analysis, building geometry data merged with construction site data, and delivery of the as-constructed model; 4D visualization; virtual prototyping; transparent, interoperable and reliable data transfer with third party applications; automated propagation of changes and integrity checking, and computer aided manufacturing and assembly. The deployment of these technologies will require open systems architectures and sharing and coordination of appropriate views of data included in the models. In other words, the presented work in this deliverable showed how the results from WP3 and WPs 4 and 5 fit into the overall holistic process and how and when they enter into the decision process.

Lack of coordination in strategic and operational construction planning process has been identified as a key main factor behind the negative impacts of urban infrastructure projects. Coordination problems commonly characterized an urban project due to the large number of stakeholders involved during the whole process.

This deliverable (D2.16) provides the background information to fulfil project objective 1a of PANTURA and all the requirements stated in DoW. A process plan of actions designed to achieve the overall objectives of PANTURA was achieved (Chapters 4-8). It builds on systematically use of resources in such way that it will enable the practitioners to clearly future?? any encounter they undertake.

The decision process of today is incoherent and lacks transparency as well as is incapable in many cases of handling a set of multiple criteria. However, the multi-criteria analysis theory was introduced as a
possible solutions and an example is provided to show its use and effects. Furthermore, the early decisions making from different perspectives have been studied through the use of three case studies, i.e. existing bridges in Rotterdam, the Netherlands, bridge over the Arno River in Toscany, Italy, and replacement of two parallel concrete bridges in Rotebro, north of Stockholm, Sweden. Furthermore, lessons learnt from the experienced gained from the case study of Government of Canary Island (GCI) were discussed.

When it comes to bridges in Rotterdam for example, three different scenarios were analysed based on the existing materials provided by the city of Rotterdam and the deliverables of WP6. The first scenario was eliminated since it resulted in namely (following to the priorities of the client) low mobility, high cost, high disturbance and long-time duration. The second and third scenarios had similar results based on the priorities of the client. Both have high level of mobility due to the direct routes. But the second scenario had low disturbance whereas the third option had high level of disturbance. Even though the scenario 3 provided a high level mobility, the low scores in other indicators (high cost, high disturbance, long time duration), this scenario has lower probability concerning to the priorities of the client. The chosen project DNA becomes the scenario 2 which contained three actions related to three different bridges; (1) construction of the new bridge parallel to the Koninginne Bridge, (2) large refurbishment of the Willems Bridge and (3) repair of the Koninginne Bridge. When it comes to action (1), the client may acquire knowledge about possible construction materials presented in WP4 (Construction techniques for existing bridges) and can use the information about advantages and disadvantages of different systems while the client is expected to gather the knowledge of the contractors in defining the tender scope prior to the bidding stage. When it comes to action (2), the large refurbishment of the Willems and action (3), the repair of the Koninginne Bridge, the client can identify the demographic profile of these two bridges through the studies undertaken within WP5 (Construction techniques for existing bridges) in relation to the formulated requirements. The case study resulted in three recommendations.

The first recommendation deals with the setting suitable weighting factors in both scenario and options for the project. By proposing suitable weighting factors, the client’s priorities can be well-understood.

The second recommendation deals with requirements priorities by the client after the client chooses the project DNA. In this step, the sustainability indicators of WP6 can be used as weighting factors as proposed earlier. This process was fictionally illustrated by WP5 on behalf of the client in order to visualize the possible action taken by the client. After prioritizing the factors, different options for renovation/strengthening the existing bridges were investigated. In WP5, several options under consideration of the city of Rotterdam were explored in order to improve the traffic flow through the city, and more specific, improve the link between both banks of the river by adjusting the route passing the Koninginne Bridge.

The third recommendation deals with the actual phasing and planning of the project prior to the construction phase. The client should carefully consider upgrading efforts concerning the potential disturbance while the second inner city route is constructed. When the client considers an alternative route which releases the existing main route between North and South, the client needs to provide an alternative route’ during construction process. This results in that when Willems bridge is under construction for the renovation work, the capacity on the existing route via Erasmus Bridge possibly get doubled. Therefore, the client needs to pay attention to the minimum on-site implementations. Corresponding to their prioritized indicators, the client should select materials, construction techniques and methods that all would increase the mobility of the commuters, cyclists, pedestrians and public-transport users within a long duration
period. The client can use the WP5 deliverable to the potentials and challenges in using different materials in consideration of minimizing traffic disruption, application time, initial costs, long-term performance and maintenance costs. Then the client can decide for the properties of the bridge upgrade.

Tools for monitoring, planning and coordination

The results to be presented from Work Package 3 (WP3) fulfil the objectives 2a and 2b of PANTURA and all the requirements stated in DoW. Communication and decision-support tool based on BIM and GIS for low-disturbance construction was developed in WP3. Lack of coordination between the stakeholders in strategic, tactical and operational construction planning process has been identified in WP2 as a key factor behind these negative impacts. Attempts to solve this issue critically depend on an effective interoperability between ICT tools from the building domain (based on Building Information Model or BIM) and the urban planning domain (based on three dimensional Geographical Information System or 3D GIS). Deliverable D3.12 is the integration platform for interoperability between various data types and applications. It is the ‘foundation and engine’ for the interactive tool. Explorative research included investigation of the feasibility of Semantic Web solutions and comparative review with other open-standard alternatives (see Section 4.3 particularly Figure 3, (D.3.12). PANTURA ICT architecture has been developed as the common framework. Based on this ICT architecture, solutions for interoperability between BIM, GIS, Urban Strategy tool, and decision-support tool (End-User Application) have been developed. Benchmarked against the existing coordination tools was achieved by State-of-the-art review which included comparative studies. Urban Strategy and the open-source BIM / GIS mixed-reality tools are products of prior research and development by TNO. The achievements obtained in the first part (D3.12) included a prototype solution that consists of: an architecture for the integration solution between BIM and GIS data and tools; an Application Domain Extension (ADE) that connects BIM data from the bridge with the computational parameters on disturbance in a GIS-based planning tool Urban Strategy; a configuration of open-source Degree 3D model server; and a query interface between the model server and the decision-support tool.

A prototype of decision-support tool, called as “End-User Application (EUA)” is described in deliverable (D3.17). In order to support decision-making in low-disturbance urban project the key functionalities of this tool are:

• It retrieves necessary information from BIM and GIS models.
• It incorporates ‘PANTURA disturbance indicators’.
• It accommodates intelligence derived from disturbance analysis in Urban Strategy tool.
• It enables different stakeholders to use the tool in combination with their sets of criteria, priorities and weighting factors depending on their roles in the decision-making (e.g. political, strategic, tactical and operational).
• It is to be deployed as a communication tool for providing clear insights into various decision scenarios and respective implications, and the comparison of these difference decision scenarios. This is in support to the stakeholders when they present and negotiate their preferences in a decision-making meeting.

Working configuration of the software are:
• Spatial environment management
• Object management
• Case management
• Multi Criteria Analysis (MCA) management
• Analysis
• Library of technical solutions

Setup of indicators/criteria are:
• General:
  - Indicator: function of data elements (questions / properties) scored on scale of 1 to 10.
  - Criterion: function of one or more weighted indicators
  - Multi-Criteria Analysis (MCA): (average of ) scores of available criteria (MCA of 2 indicators = portfolio)
• Per project/case/actor:
  - Multi-Criteria Analysis (MCA): weighted average of selected criteria
  - Selection of criteria and weights can be different per project due to project circumstances, per actor due to stakes, etc.

Direct achievement of PANTURA’s main aim to equip stakeholders and experts with a comprehensive instrument:
• based on open BIM and open GIS
• connection with an tool Urban Strategy for calculating disturbance impacts
• connection with a decision-support tool comprising generic KPIs and adjustable end-user’s criteria.

The prototype EUA as the main achievement, which is operational, has been verified and demonstrated using two case studies: 1) assembly plan of a new prefab FRP bridge in the town of Los Sauces, La Palma, Spain; and 2) a strategic plan to refurbish an existing major bridge in Rotterdam.

1.3.4 Construction and maintenance techniques for existing bridges

New challenges call for new techniques. As a result, innovative and effective bridge strengthening and upgrading techniques were proposed (WP5), as well as new methods and technologies, which provide alternative, innovative and effective methods for the new construction and renewal of bridges, including logistics optimisation, storage space rationalisation and technological worker safety enhancement (WP4).

At the start of the project, two first studies where finalised and produced the necessary information for the entire duration of the PANTURA project. These studies were: needs for maintenance and refurbishment of bridges in urban environments (D5.3) and comparative analysis of best practices (D6.4).

The goal of the first study (D5.3) was to underline the need for maintenance, strengthening and repair of bridges in Europe by presenting a general view of the condition of European bridges and what bridge authorities and owners have as their priorities when dealing with this part of road and railway networks.

The work within this study was divided into three sub-deliverables as follows:
D5.3-A) Questionnaire and analysis of the returns,
D5.3-B) Experience from concluded or on-going projects by industrial partners in PANTURA regarding the complexities and problems encountered during construction work and
D5.3-C) Literature study on strengthening and repair projects.

D5.3-A. A questionnaire was prepared and sent to 15 European road and railway administration and
The results from the returns on questionnaire were analysed and formatted. The questionnaire mainly included the following areas:

(1) Demography of European bridges: demography of European bridges with regard to bridge type, span length, construction material and age,

(2) The most common problems in bridges: the most common problems that bridge authorities in Europe are dealing with are presented,

(3) Priorities and demands: different aspects of bridge management such as client demands for the construction of new bridges in densely populated areas, demands for the maintenance (strengthening) activities of existing bridges in densely populated areas and demands for new strengthening techniques/methods for existing bridges in densely populated areas and maintenance issues are presented in this section. Upgrading of existing bridges appears to be the first option for public authorities since they seem to seek the most cost-effective way of spending the public funding. However, replacing an existing bridge with a new bridge is often the last option when all other possibilities have been evaluated. The results obtained in this area show that strengthening of decks in steel/concrete composite bridges, replacement of decks, FRP strengthening of concrete, widening of deck and FRP strengthening of steel bridges were the priorities for bridge authorities. These priorities clearly indicated that methods which were more efficient in terms of shortening the application time and also better use of materials were appreciated. Examples of methods which could fulfill these criteria were strengthen and repair using bonded FRP composites which shortened the application time and using pre-stressed FRP laminates for strengthening and repair since it provides more efficient use of materials and reduces the initial cost.

The last part of the report presents a list of case studies on completed strengthening and repair projects in Europe (mainly England). The information in this section was collected from literature where a short description of the problems, strengthening and repair solutions and the involved problems are presented. In the past two decades, rapid deterioration of bridge structures has become a serious technical and economic problem in many countries. The issue of maintaining the bridges has, therefore, become one the most important challenges in bridge industry. The term maintenance is usually defined as the systematic works performed by maintenance departments to ensure the functionality of bridges and safety of the users. It usually includes inspection, repair and strengthening and replacement of the whole or a part of a bridge. In general, strengthening and repair of bridges is preferred to replacement of structures since it is cheaper, more effective and less disruptive. The study based on the results from the questionnaire and from the relevant literature reveals that different reasons leading to the need for maintenance of bridges may be categorised as:

- Increase in traffic flow and weight of vehicles compared to original design situations,
- Harmful influence of environment such as environmental pollution,
- Use of de-icing salts especially in countries with cold climates,
- Poor quality of construction materials,
- Limited maintenance and inadequate standards,
- New safety measures.

Many bridges in Europe suffer from the above mentioned factors and are in need for strengthening and repair. For example in Sweden, 10% of roadway bridges and 23% of railways bridges owned by Swedish Transport Administration are in need for strengthening and repair. The most important demands for strengthening and repair operations mentioned by bridge owners and authorities were found to be less
traffic disruption and repair costs. Generally, the cost for strengthening and repair of bridge structures can be divided into direct costs and indirect costs. The former include the material and labour and the latter cover the costs from interruption in the bridge function such as traffic disruption. Depending on the scale, indirect costs might be several times higher than direct costs and therefore it has a high priority for bridge owners.

Deliverable (D5.3) provides the background information which was needed to focus on important priorities bases on needs in some European countries. This deliverable contributes to the project objective 4 of PANTURA and all the requirements stated in DoW.

The strengthening and repair of bridges, especially in urban areas, should be seen as multi-disciplinary operation covering not only the bridge engineering aspects such as techniques and solutions but also urban planning such as traffic and construction management. The social issues in cities may completely affect the choice for strengthening and repair solutions, materials and approach. Therefore, it is important to provide a systematic interaction between the engineering solutions and urban planning for different strengthening and repair projects in order to minimize the costs and disturbance.

Within the D5.8 (Model for management of strengthening and repair for bridges) the following results were obtained:

• An overview of the model for strengthening and repair for bridges was presented together with the criteria to be consider within the process.
• A classification of steel and concrete bridges was proposed.
• A review to the state of the art of damage diagnosis systems in which some general perspectives from Poland, Sweden and Spain was presented.
• Strengthening and repair techniques for steel and concrete bridges were described and collected in catalogues.
• An assessment methodology for the evaluation of different strengthening techniques according to the criteria previously established and a multi-criteria decision analysis was described.
• The bridge case study based on Koninginne Bridge in Rotterdam with 3 different alternatives for strengthening was evaluated in order to illustrate the assessment methodology.
• Based in the evaluation of the case study, suggestions for improvement are given in order to open the track for future developments.

Besides particular suggestions and recommendations resulting from the Koninginne Bridge case study, more general recommendations were made; such as the suggestion to collect the results of all completed MCDM’s (for example by making it a web-based tool). These results could be the object of study in a succeeding project, establishing relations between project conditions, strengthening/repair options and indicators, making it possible to compare strengthening and repair solutions independent of a project. It is important to be conscious of the fact that the list of strengthening and repair techniques listed in the catalogues, giving an overview of all strengthening and repair options available, should be kept up-to-date and could be complemented in the future. The techniques in the catalogue should be reviewed now and then to check if they are still applied, it should be checked if the described conditions are still up-to-date and new techniques should be added.

Traditional materials and techniques are usually not efficient and often time consuming. Results of inquiries
from road authorities in PANTURA project revealed that (1) minimizing traffic disruption, (2) minimizing application time, (3) minimizing initial costs, (4) better long-term performance and lower maintenance costs are the priorities when it comes to strengthening and repair methods for bridge structures.

Increase in the number of deficient bridges, on one hand, and limited financial resources on the other hand, call for more efficient materials and techniques, therefore, there is a large demand for developing new materials and techniques which are better and more efficient compared to traditional materials and methods. This deliverable (D5.8) contribute to fulfil the objective 4a of PANTURA and all the requirements stated in DoW.

The deliverable D5.20 (Toolbox for flexible refurbishment of existing bridges) aimed at developing new and improving existing strengthening and repair techniques so that they lead to; (1) shortening the application time and therefore less traffic disruption, (2) better material usage and higher efficiency and (3) application of new construction materials which have better durability properties and thus reduced LCC. The focus of the work in D5.20 has been on both developing innovative solutions and implementing innovation to solve problems and/or overcome existing shortcomings associated with existing solutions.

The core of the work in this deliverable was to use fibre-reinforced-polymer (FRP) materials in upgrading of bridge structures due to advantages that they offer compared to traditional strengthening and repair materials and techniques (D5.8). The FRP bonding technique has been around since 1970th and attracted a lot of attention as an effective and economic solution for strengthening and repair of structural elements. Numerous bridges have been upgraded using this technique around the world, providing evidence for effectiveness and viability of this method. However, using FRPs is associated with some shortcomings and there is still a need for research and improvements. Issues such as high initial cost of the material, lack of design codes, quality control during application are among the hinders. In this regard, several shortcomings have been identified in WP5 and attempt has been made to solve them. Solving these problems would certainly lead to a greater acceptance of this technique among the authorities and bridge owners. The results of the research in task 5.2 have been presented as a collection including a new design model for adhesive joints in flexural steel members, application of an innovative FRP T-profile for strengthening of concrete members, a new method for using pre-stressed FRP laminates for strengthening and repair of concrete structures without a need for anchoring systems, recommendations on using geometrical modifications in adhesive joints and a method for fast curing of adhesive joints in order to reduce the strengthening and repair operation time. Experimental verifications and field applications have been carried out to prove the applicability of the proposed techniques.

In this deliverable, a comprehensive study was performed to investigate the possibility of using new technologies in order to improve the strengthening and repair process for existing bridges, based on the main case study, the Koninginne Bridge in Rotterdam. The aim of this case study was to investigate the possibility of using new strengthening and repair techniques to cope with the existing problems. The main interest of the city of Rotterdam was to investigate the possibility of using light-weight FRP decks as a replacement to the existing heavy deck system and thus reduce the self-weight of the structure. It is recognized in the PANTURA project, both by the city of Rotterdam and by Chalmers that a light FRP bridge deck could contribute to a better, durable and more cost effective renovation of the Koninginne Bridge than a renovation using traditional techniques. By using a light FRP bridge deck, the self-weight of the structure and maintenance could be reduced. It was also estimated that this FRP renovation needs a
shorter construction period with less trouble and inconvenience. The proposed process for this case study was divided into four steps:

• Step 1; determine whether the Koninginne bridge situation, especially the available height, lends itself to the implementation of an FRP bridge deck.
• Step 2; development of the possible FRP decks and the connections to the main structure of the bridge for the three different options.
• Step 3; by using 3D modelling, the applicability of the developed FRP bridge decks on the main supporting structure of the Koninginne bridge was investigated. The following questions were of the main interests: were the FRP bridge decks sufficiently strong and stiff? Could the FRP bridge deck be strong enough to be fixed to the main construction of the bridge? Did the FRP decks and bridge construction form together a reliable, sustainable and financially attractive solution?
• Step 4; after positive results, inclusion of the FRP solutions, technically and financially, in the Koninginne bridge options as part of the Willemsbridge scenarios was presented for the client.

Deliverable (D5.20) fulfils the objective 4b-4c and partly 3c of PANTURA. The following aspects stated in DoW were achieved:

• Fundamental aspects related to the behaviour of adhesive joints between steel and CFRP laminates were investigated and verified experimentally.
• New design model for adhesive joints between steel and FRP laminates in flexural members was developed and toolbox for design of adhesive joints for steel beams was provided.
• Different configurations in order to enhance the capacity of joints were examined. Recommendations for practical use of these configurations were proposed.
• A new technology for apply pre-stressed CFRP laminates for strengthening and repair of structural members without the need for mechanical anchorage was presented. The method was verified experimentally and a field application was carried out. The possibility of strengthening and repair of structural members with regard to fatigue could be considered in the framework of application of pre-stressed FRP laminates. The beneficial effects of pre-stressing on fatigue strength of concrete and steel members were reflected in the related literature.
• An innovative solution was proposed to reduce the curing time. It was concluded from the experimental tests that the curing time could be reduced from 7 days to 2 hours using this method.

Flexible construction techniques for new bridges

When it comes to enhancing the technology for designing and constructing new bridges in densely populated urban areas (W4), three reports/deliverables were produced; the first on integrated design and engineering (D4.7) the second on techniques for off-site fabrication and on-site assembly of new bridges (D4.18) and the third on flexible assembly methods (D4.19).

The main goal for the first report (D4.7) was to develop a new design and engineering solutions, based on new materials such as pure FRP bridges and composite bridges with FRP decks. To achieve this goal firstly a study of potential bottlenecks in the process of designing and constructing composite concrete-steel bridges, as a starting point, was done. Secondly a study of existing similar complex systems was elaborated e.g. federal programs in the United States of America, similar projects and applications. Then
“composite thinking” is being introduced, as a general approach in modern design and engineering process. Building Information Modelling (BIM) tools and Design for Manufacture and Assembly (DFMA) attitude of thinking were introduced as main instruments of the integrated design and engineering system. The last step in the methodology used in the elaboration of this deliverable was to describe currently existing problems and possible solutions in the design and assembly of FRP bridges and composite structures made of timber and steel girders with FRP deck systems and related substructures with their problems, like remediation of contaminated soil. Any one of above mentioned subtasks was submitted with examples of best practices and lessons learned to enhance better understanding of the idea of the integrated system of design and engineering. The results of this task were implemented in the Rotterdam and Canary Island case studies.

First section of D4.7 constituted a deep analysis of the development of composite thinking in bridge construction through last centuries up to modern times. As an example of implemented composite thinking in the design and manufacturing process, composite steel-concrete bridges were described. The second section provided the information about DFMA methodology and possibilities for the use of BIM in the PANTURA project. Best practice and lessons learned from similar integrated projects were also presented in this section. This section was strongly interrelated with WP2 (Methods for flexible construction processes at urban sites) and especially: proactive construction process strategy (WP2.1) and systems engineering (WP2.2). Last section provided some specific data about current development in methods of off-site fabrication and on-site assembly of FRP and timber bridge structures. Also some smart techniques for piling and foundations were described. Environmental issues as remediation of contaminated soil and recommendations for avoiding vibrations and noise during the construction period were included.

Deliverable (D4.7) fulfils the objective 3a of PANTURA and all the requirements stated in DoW. FRP bridges, as well as composite timber-FRP and steel-FRP structures, are good solutions for fast installation purposes. The use of FRP materials, due to its low-corrosion properties, ensures longer life of a bridge. However, the lack of standards in FRP bridge design is still significant and is an important factor, blocking wider developments in this area.

The second report (D4.18) on techniques for off-site fabrication and on-site assembly of new bridges is very comprehensive study which contains 245 pages including four appendices. An extensive literature review about industrialized construction methods was conducted. The practical problems involved mainly during assembly were brought up and new assembly techniques involving fibre reinforced polymer (FRP) materials were proposed. The new assembly techniques were developed by transferring knowledge from other sectors for potential use in construction with an emphasis on design for manufacturing and assembly. These techniques were evaluated taking into account the voice of the customer. After evaluation, the promising techniques were further studied by advanced numerical analyses. Laboratory testing was performed on one potential connection between FRP bridge deck panels and it was found that this connection was sufficiently stiff and strong for use in bridges, and it enables immediate assembly. The potential use of this technique was demonstrated in one case study bridge, Koninginne Bridge located in Rotterdam, the Netherlands. Design recommendations for the FRP-steel composite bridges were developed. In addition, a life-cycle assessment and life-cycle cost analysis was performed to determine the cost efficiency and environmental impact of the new proposed solutions compared with traditional bridge construction methods.
Different off-site manufacturing techniques for FRP structural elements were presented and these were demonstrated for FRP decks. Six types of deck were designed. Their prototype models were made using infusion process. Three of them were tested in laboratory. Data from these tests and experience of the production stage contribute to the selection of the best concept. As a result, much larger deck panel than these tested prototype was made and re-tested. The failure of the large panel was initiated by brittle fracture in the adhesive layer between two halves of the panel. The maximum utilisation factor of the laminate was 44% at the failure load. The results confirmed the correctness of the adopted technological solution, the material and the design. Despite the very low weight of the panel (83 kg/m²), Serviceability limit state (SLS) and ultimate limit state (ULS) verifications were not exceeded. However, further optimization of material or design is possible. The developed deck panel demonstrated sufficient capacity and stiffness and can be considered as an alternative to conventional reinforced concrete deck plate, where the distance between girders does not exceed 2.40 m.

Several connection concepts were developed for the assembly bridge elements focusing on panel level and system level connections. A close collaboration between the client (TRV), contractor (Acciona), manufacturer (Mostostal) and designer (Chalmers) contributed to the development of connections, where the main goal was to deliver a quality product by focusing on the client requirements. The developed connections were evaluated by means of a matrix which was developed specifically for the purpose of this work. Further detailed evaluation of the connections was focused on the panel-level connections due to resource and time limits. Detailed numerical analyses and an experimental test were performed on one of the developed panel level connections. The laboratory test demonstrated that the developed connection meets the stiffness and strength requirements. The developed connection has a potential for application in bridge construction with focus on swift on-site assembly. The assembly of the deck panels with the developed connection is immediate and the total construction time on-site can be reduced by more than 20%.

Structural analyses of two different FRP-steel composite bridge concepts were performed by means of finite element method in order to provide recommendations for FRP-steel bridges. The main results can be summarized as follows:
- The design is guided by serviceability limit state (SLS) rather than ultimate limit state (ULS) verifications. The FRP deck turns out to be very deformable as compared to traditional reinforced concrete decks. Consequently, it is necessary to introduce steel diaphragms and bracings to provide the structure with the required overall stiffness;
- Simplified FE models can be defined, enabling a relevant reduction of computational costs. Such models can be used for preliminary design and global verifications, while for local checks on the FRP deck elements refined models should be used (possibly, limited to single portions of the bridge deck);
- The advantages of composite action over non-composite action may be relevant in terms of both maximum deflections and von Mises stresses. It is therefore advisable to develop connection systems that assure an effective and durable collaboration of girders and deck;
- The dynamic effects should be considered very carefully, in particular for long span bridges, whose natural frequencies may fall inside the critical ranges for vehicle transit. Furthermore, very large shifts in the natural frequencies have been observed when going from the unloaded to loaded configurations. It is suggested that the dynamic behaviour of FRP-steel composite bridges should be investigated through more refined dynamic analyses.
A conventional steel/concrete bridge concept was compared to three different concepts using FRP bridge deck and one concept with a steel sandwich deck in terms of life-cycle cost and environmental impact. Two different scenarios were compared, where in scenario 1 the bridge is a new construction project and in scenario 2 the bridge is a replacement bridge project. It was observed that FRP-steel bridges were more favourable in bridge replacement scenario.

The results suggested that a conventional alternative with lower production costs and longer production time could be more profitable, as long as the affected traffic volumes was limited to the size considered in this study. However, considering a more complex traffic situation, such as those in densely populated urban areas with high traffic volumes, favors consideration of prefabricated alternatives, such as FRP, with a higher investment cost but a significantly shorter construction time. A combined effect of a busy traffic situation, decreased FRP pricing and a low discount rates would definitely benefit the FRP alternatives. The results from the LCA showed that the steel/concrete bridge had a slight advantage regarding the total normalized impact over the other design alternatives. However, all categories except freshwater eutrophication favoured FRP alternative 1 and 2 when studied individually at midpoint level. The normalized result indicates that a simplified LCA analysis considering only one impact category might be misleading.

Deliverable (D4.18) fulfils the objective 3b of PANTURA and all the requirements stated in DoW.

The last deliverable related to WP4, i.e. D4.19 (290 pages including two appendices), on flexible assembly methods produced a wide range of technical solutions from prefabrication, ICT and robotics. Recent developments in prefabricated elements based on traditional or more recent materials with low weight-to-resistance ratio make it possible to pre-assemble larger elements or to reduce the need for heavy lifting equipment while improving constructability and working conditions on-site. The ICT and robotics solutions identified and analysed in the study can contribute to:
- improve management of resources/persons,
- reduce maintenance costs,
- increase level of safety,
- increase effectiveness of construction process,
- improve mounting/moving elements
- accelerate work on-site (reduce time of work),
- improve management of information/organisation on-site,
- ensure safety level of environment,
- avoid administrative fines,
- detect defects in design elements.

Many of the studied solutions or the materials they are based on are commonly used in production and manufacturing in other industries but scarcely in construction. Others have already been applied with success in civil engineering projects in some countries and would deserve wider dissemination. By analysing different innovative solutions using the SWOT approach, the following strategies have been suggested to overcome their remaining weaknesses and to gain acceptance for them by the different actors of civil infrastructure projects:
- Work on standardization and on the development of design codes covering the use of new materials (e.g.: FRP materials, adhesives, etc.) and specific structural solutions based on these materials
• Research on material durability and means to improve material properties (e.g.: improve fire resistance for FRP materials, high-strength & fast cured adhesives for use in bridges, hardiness of ICT products, etc.)
• Research on possibilities of reusing or recycling new materials (e.g.: FRP materials, adhesives, etc.) to bring to regular practice in order for the technology to be more sustainable
• Information/Presentation of the technology and demonstration projects to bring acceptance to bridge authorities
• Include life-cycle cost analysis in the procurement stage and not base the decision only on the initial cost. Increase the awareness of potential buyers that the solution will bring significant savings in the long term
• Develop and include life cycle assessment methods to illustrate objectively the benefits of the technology
• Training / Education of the workers and provide material safety data sheets for handling of new materials (e.g.: adhesives) and precautions to be taken in case of injuries. Encourage the development of manufacturing companies to improve competitiveness.

When using prefabricated elements flexibility decreases compared to traditional on-site bridge construction and late changes become harder to implement, which requires a good planning to have an even flow at the site and to avoid unexpected events. Besides, run-of-the-mill processes should not become overlooked due to their apparent simplicity when implementing new methods. With that in mind, the different stages of the assembly process have been studied to identify the critical issues.
Based on these critical issues, precise procedures were developed for different aspects of urban construction and ICT technologies, assembly techniques and organizational patterns are proposed to enhance and optimize the processes existing within a construction site. Concepts such as logistics optimization, storage space rationalization or technological worker safety enhancement were thoroughly studied and ideas for improvement have been proposed as a result of the analysis.
Following the PANTURA procedures, the contractor shall achieve a highly efficient construction site where all activities are integrated and specifically designated not to interfere with each other whenever possible:
• Tools for management and follow-up of component logistics shall be available, reducing waiting times and facilitating supply chain management while maintaining on site storage space at reasonably low levels.
• Health and safety procedures, powered by electronic devices, shall be easily applied thus guaranteeing both regulations compliance and workers’ wellbeing.
• Traffic within the site shall be optimized for non-interference and safety, and outside traffic disturbance shall be minimized
• Assembly processes shall be fast, safe and cost-effective thanks to the application of robotics and information technologies. Use of auxiliary means such as cranes, piling rigs or concrete pumps shall be optimized, reducing idle through precise assembly planning.
• Electronic support systems management shall be centralized for best performance.
• Crisis and threat to human life situations shall have clear and defined procedures to minimize risks. They shall be reminded to involved workers by means of electronic panels in case of need, thus preventing the possibility of blanking out due to panic or pressure.

Deliverable (D4.19) fulfils the objective 3c of PANTURA and all the requirements stated in DoW.
EU directives with supporting documentation for the construction of urban bridges with health and safety of residents and workers as a priority were developed in WP6 (D6.21). Guidelines for national policies on critical elements necessary at the national perspective for the successful implementation of health and safety concepts to be used have also been developed. Finally, project level measures to be performed at all 10 lifecycle phases of a construction project have been developed to integrate health and safety concepts at every phase of the bridge lifecycle. In an effort to quantify the actual health and safety effects of an urban bridge construction project, indicators based on ISO 21929 and CEN TC350 were developed to be used throughout the project lifecycle to quantify the health and safety aspects of the bridge project. Similarly, EU directives with supporting documentation for the construction of urban bridges in the prioritized reduction of greenhouse gas emissions over the lifecycle of the bridge are also presented in this report. Guidelines for national policies on the necessary critical elements for the successful implementation of greenhouse gas reduction concepts to be used at a national level are also presented. For on the ground implementation of these directives and policies, project level measures to be performed at all 10 lifecycle phases of a construction project have been developed to integrate GHG reduction at every step of the bridge lifecycle. Indicators were also developed to quantify the ability of the bridge project over its lifecycle to reduce greenhouse gas emissions, these indicators were based on ISO 14040 and the results of the ETSI Bridge lifecycle optimization project.

In terms of structural reliability the PANTURA ensures that application of sustainability, health, safety, and ICT integration at the very least maintains current specifications for structural reliability. As a result, this research illustrates that sustainability and disturbance criteria can be applied without a negative effect on structural reliability. Specifically, innovative new materials with documented structural reliability were sought out. As a result two promising technologies already in use are proposed to reduce the disturbance and decrease the emissions associated with bridge construction and maintenance.

In terms of ICT integration significant progress was made during the PANTURA project with regards to the integration of ICT concepts such as GIS and BIM into a unified multiple criteria decision analysis tool. This tool is intended to be used by stakeholders of an urban bridge project to make informed decisions with regards to aspects of disturbance in a bridge construction though traffic simulation software (such as urban strategies). Additionally, the results of this study find that there is significant potential for mobile ICT applications for use in user based real time geographically based documentation of disturbance violations. Finally, the recommendation of this report is to actively implement the use of complete lifecycle costs for bridge projects including the social (disturbance) and environmental costs during the tendering stage of the bridge lifecycle. Specific efforts should be made within the Life cycle cost (LCC) to capture the environmental impacts of Life cycle Assessment (LCA) significant materials (Concrete, steel, timber, and asphalt) as well as capturing the social costs associated with health (Noise, vibrations, dust, and reduced mobility) and the safety costs (Worker safety and resident safety). As a result, new measure or standard has been contributed to the knowledge fields of health and safety and sustainable development.

Deliverable (6.21) fulfils the objective 5c of PANTURA and all the requirements stated in DoW.

Final remarks

The ambitious over-all objective: low-disturbance construction has been achieved by approaching the problem from an interdisciplinary perspective. The main results include: proactive procurement process, multi-criteria indicators and decision analysis, an integrated ICT decision instrument, and innovative and fast bridge construction, strengthening and upgrading techniques.
Through the application of the PANTURA procedures, construction sites can be turned into high-tech areas, where processes are streamlined, safety is paramount, nuisances are minimized, and latest advances in ICT technologies are used to facilitate decision making, coordination and management. This in turn will allow achieving a high degree of effectiveness during the construction process and as a logical consequence lead to the success of the projects.

Potential Impact:
Training and Dissemination of PANTURA Results

The aim WP7 was to assure the sustainable knowledge transfer and implementation of PANTURA results to clients, the construction industry and other stakeholders and to stimulate new market opportunities and knowledge development. The following main dissemination activities have been the core of the transfer and implementation of PANTURA results.

Stakeholders’ Panel (SP)
The principle goals for the SP was to provide input for state-of-the-art studies on best practices, needs and demands when it comes to construction process and techniques at urban construction sites. All consortium participants have invited representative stakeholders to participate in the stakeholders’ panel. During the periodic consortium meetings stakeholders of the host country were invited to a workshop with the consortium members to discuss progress, implementation and dissemination. During the duration of the project, PANTURA partners had regular contact with the stakeholders in their own member states.

Training documentation and pilot training courses
The training documentation consisted of a number of structured PowerPoint presentations, with supporting documentation, based on the other project deliverables. All research partners contributed to the development of the documentation; the different task leaders being responsible for the delivery of the documentation in the approved standardised format. The research partners presented the instruction material in pilot courses to participating stakeholders (public bodies), other invited stakeholders and personnel at the participating research partners, who are going to use the knowledge in daily practice. The results of these pilot courses (one by each research partner) were used to improve the instruction material.

PANTURA Public Website
The central information retrieval mechanism is a public website containing a database with background information, working reports, deliverables, presentations and publications (articles and brochures). All partners have contributed to the contents of the PANTURA public website. The website is hosted and maintained for duration of XX years by DEMO as WP leader.

Dissemination and implementation roadmap
The implementation guidelines and an implementation roadmap were developed to organise and structure the dissemination process to support the maximum, sustainable knowledge transfer of PANTURA results to clients, the construction industry and other stakeholders and to stimulate new market opportunities and knowledge development. The central aim was to actively stimulate stakeholders to use the new knowledge in practice. Participants in PANTURA made the greatest possible effort to ensure that an electronic copy of the published version or the final manuscript is free and electronically available to anyone through this repository: immediately, if the scientific publication is published “open access”, i.e. if an electronic version is also available free of charge via the publisher, or within 6 months of publication. The results will be disseminated by presentations, conferences, brochures and through the PANTURA public website.
Aim of exploitation plan and implementation roadmap (Impact)

The aim of the PANTURA exploitation plan and implementation roadmap is to establish the use and the commercial exploitation of the knowledge gained and the tools and process procedures produced in the PANTURA project. For a successful project lifecycle, careful dissemination and exploitation strategies are essential. While dissemination activities were performed from the start of the PANTURA project, the exploitation strategy concentrates on the project’s results afterwards to:

- Ensure that the developed products are used as the basis for further technological development:
  - By the partners;
  - By new projects;
  - By R&D communities
- Ensure that the services and products developed are used in a commercial and corporate context.

The exploitation plan is aiming to set up the successful exploitation of the results and defines the strategy to exploit the results of the project at consortium level and at individual partners’ level. The Implementation Roadmap addresses the basic condition for a successful exploitation of the results in terms of collaboration at consortium level, establishment of joint-ventures and other forms of collaboration and future developments regarding research and product development. Each partner has specified its own exploitation plan to take advantage of both the knowledge acquired throughout the project and its tangible results, presented in D7.22.

Exploitation and Implementation per Work Package

In this paragraph the exploitation potential is presented for each work package. We look at the market for the PANTURA products, the business objectives and key exploitation intentions and the general marketing strategy.

WP2: Methods for flexible construction processes at urban sites

Market

The results of WP2 aim to meet the increasing demands for higher quality, shorter construction times and reduced environmental impact through a proactive integrated strategy. The importance of the urban areas will increase further in the future. Seto and Shepherd, (2009) state that “in 2008, the global urban population exceeded the non-rural population for the first time in history, and it is estimated that by 2050, 70% of the world population will live in urban areas”. Hence, a large part of future construction sites will be situated in areas surrounded by existing buildings and infrastructure. In order to avoid unnecessary disturbances to the surrounding, and at the same time increase competitiveness, disturbances need to be acknowledged and addressed. The different disturbances of the surroundings affect the various stakeholders in separate ways, which is important to consider reducing negative impact. The strategy assists the actors involved in infrastructure construction (bridge in particular) projects at different levels and phases.

Business objectives

The main WP2 business objectives are to achieve higher quality, shorter construction times and reduced environmental impact in infrastructure construction projects. This will have beneficial effects for all actors...
by also reducing the risks and limiting the disruptions and disturbances. The results can be used internally by companies, to make the processes more efficient and create new innovative products and services. They can also support the public bodies by providing means of taking more informative decisions as well as improved communication with the stakeholders and the public at large.

Marketing strategy
To meet external drivers and pressures (international competitors, climate change, increasing urban population, aging infrastructure, increasing demands on mobility etc.), the PANTURA results offer the companies and organizations the necessary methods and tools. By a proactive approach, in contrast to a reactive one, new innovative solutions can be found that combine the strengths of people, processes and technologies. More complex projects are anticipated in the future which requires a better understanding of economic, ecologic and social sustainability parameters. The results presented in WP2 help the partners gain a competitive advantage.

WP3: Tools for interactive monitoring, planning and coordination
Market
The results of the WP3 will be used to assist potential clients and other stakeholders in deciding on construction projects in densely populated urban areas with the aim of a zero negative impact and with the most efficient use of resources. In WP3, an interactive tool for monitoring, planning and co-ordinating complex urban projects was developed, that supports flexible construction processes at urban sites. The decision making tool is crucial to clarify the benefits of the overall PANTURA research results regarding the innovative solutions for the design, engineering and assembly of new construction and the renovation of bridges in cities.

Business objectives
The main WP3 business objective is to sell, license or use as a consultancy tool the software developed in WP3 and by doing so, equipping the authorities, stakeholders and experts with a comprehensive software instrument to prepare construction projects in densely populated urban areas in the most effective and efficient way, in the shortest possible time, with the most efficient, sustainable use of resources and with zero disturbance and disruption for the urban environment and urban life of the inhabitants.

Marketing strategy
The core of the marketing strategy is to sell the software tools as part of (already existing) consultancy services in combination with software licences (SAAS). Consultants and research institutes can use the tools to support their large public clients in investigating the possibilities of sustainable and hinder free construction projects in densely populated urban areas and to compare the benefits, disadvantages and cost of different alternative solutions. Combination of the software tools with existing consultancy services as investment appraisal, with its focus on lifecycle cost comparison and the implementation of performance based contracts, with the need for performance assessment and monitoring services, are especially promising. The same holds for the integration of BIM-models in the real estate information structure of client organisations, resulting in a framework/container that will be configured and filled with project related data and environment (the commercial opportunity is not the sales of the framework, but the use in a consultancy context, combining software sales with implementation services). Contractors and other members of building consortia can use the software to show how they are able to meet the
client’s demands with their services and product offered.

WP4: Flexible construction techniques for new bridges

Market

The results of the WP4 will be used in the road sector (secondary elements), engineering structures sector (bridges, overpasses) and earthworks (retaining walls). Most important sector is the engineering structures segment due to the size of the market and the value of contracts so that cost and labour reductions are very significant. At the same time this technology can be very interesting for local authorities as rapid deck exchange technology for the construction of small bridges and footbridges.

On the market there are companies that, like the contracting companies participating in PANTURA, offer a wide range of construction services. These companies compete in public tenders, financed from the national budget, where low price and short time of execution determines the winner. That is why the reduction in costs of construction and robotics in the assembly process plays a significant role in enhancing the competitiveness of the PANTURA partners. Besides that, FRP is a new technology on the market that in the future effectively could replace steel and concrete at some construction work such as replacing of the bridge deck. Lately we see in building magazines and on conferences more and more articles and presentations on the use of composites in road infrastructure. Not only academics but also entrepreneurs are increasingly interested in using FRP materials in construction.

Business objectives

The main WP4 business objective is to stimulate the production and implementation of composite bridge assembly which brings about many favourable changes comparing to current process. This gives PANTURA partners substantial benefits above its competitors. The most important benefits are:

• Reducing labour off-site and on-site costs by the automation of the processes, and use of ICT in the manufacturing, logistics and assembly processes.
• Avoiding redoing the work and “bad-quality” costs due to improved quality management obtainable with the new technologies and industrial processes to be developed.
• Reducing wasted material costs by improved overall manufacturing efficiency;
• Reducing energy costs by optimized consumption and needs of the new industrialisation process
• Reducing transport cost due to the lighter weight of FRP components compared to concrete ones.

Marketing strategy

The core of the marketing strategy is to recognize the customers’ needs, shaping them, and then create the product or a service, which meets their demands.

At the moment, the economic trend in the construction market in most European countries is negative, but every sector has its good and bad periods, and there are signs of a slow recovery. That is why it is important to look forward and take advantage of the market interest, to strengthen one’s position and to be ahead of competitors. This will result in effects in the future. FRP construction for transport infrastructure seems to be an area in which PANTURA partners can be successful market leaders, because of the PANTURA project results.

WP5: Flexible techniques for maintenance and refurbishment of existing bridges

Market

The results if the WP5 will be mainly used in the infrastructure (bridge) sector. The aim of the WP was to
promote new strengthening and repair techniques which lead to more sustainable solutions and provide practical guidelines and recommendations towards more efficient upgrading methods. The need in the bridge market is due to the fact that a large stock of existing bridges is very old and cannot comply with the requirements in the new design codes. Today, over 50% of our bridges in Europe are older than 50 years and in need for some kind of strengthening and/or repair action. Existing traditional strengthening and repair techniques are usually labour intensive, time consuming and not efficient. Therefore, there is a need for improved solutions. In this context, WP5 promotes application of FRP materials for strengthening and repair of bridge structures. As a contribution this WP provides improvements with regard to application of FRPs by introducing new techniques such as application of pre-stressed CFRP laminates, innovative FRP sections and a method for fast curing of adhesive joints which all lead to better use of material, more efficient strengthening and repair scheme and shorter application time. Application of FRPs for strengthening and repair is a well-established and yet growing market. Due to rather high initial cost of FRPs, innovative solutions resulting in less material usage or more efficient use of the material will be appealing to the market. On the strengthening market, there are many companies which compete in this sector and less material usage or shorter application time would be an added value for the services they provide. WP5 provides the tool for companies acting in the strengthening and repair market to improve their competitiveness.

Business objectives
The main business objective of WP5 is to promote application of FRP composites for upgrading of bridge structures by providing innovative solutions and improvement of existing methods taking advantage of FRPs. The added values provided by PANTURA are:

- Increasing the efficiency of strengthening and repair schemes by introducing more accurate design models
- Reducing the amount of utilized FRP material by introducing a technique for using pre-stressed FRP composite laminates.
- More efficient use of FRPs by introducing an innovative T section
- Shortening the application time by introducing a method for fast curing of adhesive joints between FRP materials and structures.

Marketing strategy
The procedure for marketing strategy was to map out the customer’s needs, identifying the bottle neck points in the market and specify the areas in which an improvement or innovation could be made and produce a service or a product which meets the market needs. The strengthening and repair market using FRPs has been a growing market in the past 30 years and the increasing number of the bridge structures strengthened or repaired using these materials prove the potential of FRP strengthening. It is anticipated that by introducing improvements and innovations in this market, the method would be even more appealing and obtain more acceptance. The marketing strategy for further developed strengthening technology (using pre-stressing techniques) will be through establishment of a new SME company with focus on providing information to public authorities and private design and construction companies. Workshops advertising the technology have already taken place. Strategic partnership between the new company and established building contractors within strengthening and repair sector will together promote the new technology.
WP6: Benchmarking, measures, and standardization

Market
The results of WP6 provide valuable research in terms of the challenges being faced at a local level but also on a European level where the construction and maintenance of large scale infrastructure with respect to disturbance and sustainability are increasingly important. Additionally, the work conducted within WP6 illustrates the potential for incorporating LCC and LCA concepts to provide sustainable solutions which can be quantified in monetary values. The market for such services lies in both the private and public sector. Within the public sectors the research has shown that the active quantification of sustainability and disturbance criteria by infrastructure owners is still in its infancy, as such additional work must be done to provide the public sector with “buyer’s” competence in terms of what the owners should be expecting and ordering from the private sector. In terms of the private sector, willingness to incorporate sustainability criteria has been shown. However, the private sector still needs the appropriate incentives to actively incorporate sustainability and disturbance criteria into projects. Should the incentives present themselves, then the PANTURA methodology could prove to be one tool adopted by the private sector to provide sustainable and reduced disturbance solutions to the public sector.

Business objectives
In terms of business objectives, the skills gained through the PANTURA project illustrate that sustainability evaluation of the built environment is a growing field, and one that will likely grow in the future. Specifically, the ability to take weighted and appropriate decision with disturbance and the environment in mind in terms of the lifecycle of the bridge will become very important. As a result, consulting opportunities as well as continued research opportunities are foreseen as likely results of the research from WP6. Industry partners (external from PANTURA consortium) have expressed interest in continued development of the technology with BIM. As a result, significant opportunities may be available with continued development of multi-dimensional BIM models potentially incorporating sustainability criteria and disturbance together with 5 D (3D with cash flow and time) BIM models.

Marketing strategy
The marketing strategy of the tools and technology developed in WP6 will focus on spreading the knowledge and technology to both public and private partners through existing relationships. Workshops advertising the technology have already taken place and interest has been shown in using these technologies both in continued university research as well as trial implementation in large scale infrastructure projects. An important aspect of the marketing strategy will lie in highlighting the applicability of the PANTURA sustainability approach to large infrastructure projects such as roads, tunnels, etc. as this will provide additional avenues for exploitation. Strength of the PANTURA technology and process lies in its existing connection to BIM.

Exploitation per Partner

Industrial Partners

• Mostostal Warszawa SA. (MOS), PL
• NCC AB (NCC), SE
• Acciona Infraestructuras, S.A (ACC), ES
The exploitation plans of the PANTURA industrial partners concentrate on the use for further internal research and the application of the results in infrastructure design and build projects. The emphasis lies for the industrial partners on the results in WP2 on Methods for flexible construction processes at urban sites, and the results of WP4 and 5 on flexible techniques for new construction, refurbishment and maintenance.

SME’s

- Darellsoffice B.V. (DRL), NL
- DEMO CONSULTANTS BV (DEM), NL
- AICE Consulting SRL (AIC), IT

The SME’s in PANTURA are – apart from being SME - quite different in nature and business concept. Darellsoffice concentrates on project management support, with the main exploitation focus on Methods for flexible construction processes at urban sites. DEMO Consultants is a software developer which concentrates on research and tools for real estate management and construction. DEMO will concentrate on the exploitation of the results of WP3 Tools for interactive monitoring, planning and coordination. These results will be incorporated in the DEMO RE Suite. SME partner AIC intends to use the results of D2.10 and D2.11 to develop and update products and services used for consultancy in tender procedures for private and public clients. Results of D2.16 will be integrated in models and methodologies used by AICE. The knowledge and results of WP4 and 5 will be used for design, engineering and consulting services to private and public clients. The deliverables of WP3 and 6 will be used as reference document for the design of new bridges in urban areas. PANTURA results will also be used to inform public clients and the construction companies.

Universities and Research Institutes

- Chalmers University of Technology (CTH), Göteborg, SE.
- SINTEF (SIN), NO
- TNO (TNO), NL

Partner CTH being an university will focus the exploitation of PANTURA on including the results in education of engineers and future research. The prototype developed in WP3 will be disseminated in several student projects. The results of WP4 and 5 are the core topic of CTH and will be used in new research projects. The multi-criteria analysis developed in WP6 will be incorporated in education of engineers and used as reference document for new research projects. SINTEF intends to incorporate the indicators developed in WP6 in LCC and LCA concepts to provide sustainable solutions which in combination with results D2.11 and D2.16 have high potential for development, engineering and consulting services to the building industry and public clients. SINTEF will use the results of WP4 and 5 for internal research purposes and for consulting services to public and private clients (for example to provide international project services together with the Norwegian Transportation Network (NTN) and the Norwegian Public Roads Administration) and will disseminate the knowledge to the partners involved in the Norwegian Ferry free E39 project. Dissemination and training events by SINTEF have shown a willingness in using these technologies both in continued university research as well as trial implementation in large scale infrastructure projects. TNO intends to use the knowledge and results of WP2 for internal research purposes; for research, development, engineering and consulting services to
public clients; as well as an input for standardization in public procurement EU directives. TNO will explore possibilities to license the developed ICT inter-operability solutions IN WP3. The results of WP4, 5 and 6 will be used for internal research purposes; for research, development, engineering and consulting services to public and private clients; as well as an input for BIM/GIS open standardization as well as an input for technical standardization especially in the field of sustainable urban environment / smart cities.

Local Authorities

• Gobierno de Canarias (GCI). Consejería de obras publicas y transporte. ES
• Trafikverket (TRV) (Swedish Transport Administration), SE
• City of Rotterdam (ROT), NL

Partners GCI and TRV have not made an individual exploitation plan. However the workshop on PANTURA results for local road and bridge authorities in Las Palmas (Las Palmas de Gran Canaria; 30th October 2013) showed the interest and willingness to implement these results in the daily practice. At the Stakeholders’ meeting in Madrid, TRV explained how the will implement the PANTURA results for future project development, procurement and management. The City of Rotterdam will use the results of WP2 in further development of her public engineering skills to involve market parties more and earlier in infrastructure projects. The results of WP2 help the responsible public organizations on short-term to achieve good results as the growing complexity of society and urban infrastructural systems require new design and construction processes. WP2 shows the potential of Integrated design and delivery solutions (IDDs). The tools developed in WP3 are the missing link in front of the infrastructural life cycle. In view of the considerable social importance, City of Rotterdam will take initiative to encourage further development of this EU PANTURA Urban Infra Strategy tool.

One of the main obstacle in consideration and decision making processes is the growing distance between decision makers and infrastructural technology. The now available prototype has potential to become an indispensable tool. City of Rotterdam will collaborate in the further development of this tool. In the Netherlands the city of Rotterdam is leading in the appliance of composite bridges. Rotterdam has realized over the last years 67 small composite bridges, steel composite and full composite. City of Rotterdam will use the results in WP4 and 5 in the coming years to scale up the appliance to larger composite bridges. About 70 composites bridges now are in the phase of development. The developed toolbox in WP5 will be used by the engineering department of the city of Rotterdam in the maintenance process of the urban bridges. The toolbox helps to apply new materials and constructions and offers interesting solutions for intensively used urban bridges. The toolbox will be used in the urgent upgrading of the Koninginne Bridge and other historical important urban bridges. The results of WP6 on indicators provide an important contribution to better understanding of the public clients in all for careful, low-disturbance and sustainable integration relevant criteria. The results will be implemented in the Rotterdam sustainability program and the public supervision and monitoring n infrastructural construction

List of Websites:

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