STRATEGIC RESEARCH AGENDA FOR THE EUROPEAN UNDERGROUND CONSTRUCTION SECTOR

Draft, October 2005

European Construction Technology Platform (ECTP)
www.ectp.org
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STRATEGIC RESEARCH AGENDA FOR THE FOCUS AREA OF UNDERGROUND CONSTRUCTION

October, 13th 2005.

PREAMBLE

This document is the Strategic Research Agenda (SRA) for the Focus Area of Underground Construction (FAUC) established by the European Construction Technology Platform (ECTP) that addresses the research needs of Europe in the field of Underground Construction over the next 25 years, and sets out the likely directions of technological and organisational changes that will need to be converted into specific research programmes over the coming years.

In the real world the demand for R&D is, quite correctly, driven by market forces of today, rather than by the need to turn into reality the visions for tomorrow. It is important - the existence of the vision notwithstanding - that this remains substantially the case.

Essence of the Strategic Research Agenda is to establish long-term research objectives, and to organise research actions corresponding with both market driven innovation and the long-term vision. A well crafted Strategic Research Agenda will closely maintain the balance with both of these objectives.

The SRA defines the research that needs to be carried out to achieve the vision 2030 whilst at the same time taking account of market forces.

The purpose is to guide and stimulate all those interested with the relevant research programmes, whether from a governmental, industrial, social, funding, policy or regulatory perspective. It is not to list specific research programmes or collaborating actors, it is to pave the way for future research by clear sets of directions and priorities.

Ultimately, the success of the document will be judged on just two criteria, by two very different stakeholders:

- The users will expect to see the realisation of the vision, while
- The researchers will look for a framework where their talents can contribute and respond to the needs of the market place.

This draft Agenda is the first of a series of agenda documents aimed at delivering and updating a long-term view of research priorities and needs. It has been prepared by the Underground Construction Focus Area Members.
1. Introduction

European economical spaces are today like huge crowded organisms, continuously evolved and linked by congested streets, roads, rails and communication networks. Most of today’s cities can not include modern services unless they sacrifice or destroy the scarce public and inherited monumental spaces, environmental culture and ambiance, which has been used as cultural reference, from one generation to the other.

A steadily increasing market value of the land property in the cities constitute another important driving force to better exploit the underground space, which is today still widely underused compared to the space at ground level. Therefore the main goal is to improve citizen’s quality of life, through the conquest of the third dimension, in buildings, networks, and in general for the built environment.

Another goal is to link European countries cities and villages, with a network of new intelligent technological transport systems. This has to be able to cope with the European citizens’ vision for the year 2030, with a substantial improvement in safety, comfort and environment protection.

If Underground technologies are fully developed to their implicit potential the cities, natural obstacles like rivers, mountain ranges, and forests will not be obstacles any more the natural alternative will be to by-pass them underground; this solution could be applied in the future to protect sensitive natural environments and to avoid land rights acquisition to implement new transport infrastructures.

Underground construction operates in a very competitive international environment. For example, countries such as Korea and Japan have long learned from European experience and are investing significant research funds in innovative technology, in order to take a leading role in the world. If the European industry sits back and allows this to happen, then its competitiveness will be lost and the economic damage would be substantial. European construction will only have a real chance of being competitive, if
we gather all available research clusters in Europe and create a critical mass in order to achieve a breakthrough in the application of innovative technology.

In the real world the demand for Research and Development is, quite correctly, driven by market forces of today, rather than by the need to turn into reality the visions for tomorrow. Essence of the Underground Construction Strategic Research Agenda is to establish long-term research objectives, and to organise research actions corresponding with both market driven innovation and the long-term vision.

A well crafted Strategic Research Agenda will closely maintain the balance with both of these objectives: by creating a consensus between stakeholders on priority objectives, and by organising the progression from today’s reality towards the vision’s objectives.

This Strategic Research Agenda document is the result of quite a complex elaboration process, aiming at reaching the best possible consensus of all stakeholders of the Underground Construction Sector on a reduced set of priorities. The Vision for 2030 should remain globally unchanged with time, but all main drivers for research will change continuously: the global context, technology, market forces. Therefore, this SRA is not crafted for ever: role of the ECTP FAUC will be to keep this document regularly updated.
2. The context of the European Underground Construction Sector

2.1. Societal needs

The current picture of the European built environment presents a stark contrast between the best technological achievements like the implementation of new transport technologies like the MAGLEV (magnetic levitation vehicles), the Channel Tunnel and the new metropolitan lines across Europe and the most beautiful examples of cultural heritage, like the alpine tunnels, co-existing with huge amounts of substandard infrastructure, in the crowded cities of the main capitals.

Our built environment shapes our society, the way we live, work, entertain and move around. The development of a sustainable built environment for all is essential for the realisation of a society based on equal rights and opportunities. Many persons in the society of today depend on an accessible built environment in order to live autonomous and active social and economic lives. This number will increase significantly with the demographic changes in Europe, making a “design for all” approach of particular relevance.

Maintaining, upgrading to a common standard, re-inventing this huge asset accumulated over past history is one of the main challenges confronting the enlarged European Union. Taking care of an omnipresent heritage while building a new society with high quality standards required by increasingly demanding users is a specific challenge of the new Europe, which place on the Construction Sector of unavoidable and urgent social demands:

- Creating a built environment comfortable, accessible and usable for everybody
- Improving health, safety and security of the built environment in whole life cycle
- Preserving environment, cultural heritage and natural resources
- Enhancing the urban spaces
- Optimizing the cost of the life cycle for the built environment
Promote the sustainability in our environment, people safety during the construction stages and the use of facilities and infrastructures. Generate new empty spaces for the citizen’s enjoyment. Transform our congested, noisy and polluted urban environment in agreeable areas to live. Places designed for people and completely developed for human beings.

These aspects need an approach of the services to the citizens being especially careful with people disabilities, people with reduced mobility, old people and children, having in account at the same time the actual multiculturalism of our society.

2.2. The European policies

The first requirement in the Construction Sector is to take its share and strive for the strategic goals of the European Policy:

- The **Lisbon strategic goal** (2000) to become by 2010 “the most competitive and dynamic knowledge-based economy in the world.

- The **Barcelona goal** (2002) of raising Europe’s overall level of research investment from its current level of 1.95 % of GDP to 3 % by 2010, of which two thirds should be from private sources.

- The **renewed Lisbon Strategy** (2005), with ambitions for Europe to be a more attractive place to invest and work, sharpen by knowledge and innovation, creating more and better jobs (COM(2005)24, 2/2.2005).

2.3. New Opportunities for Change Offered by Technology

We have perceived that the construction sector has been more cautious than other sectors with regard to adopting technological innovations and new working methods, which can be seen most clearly in the case of construction projects whereby in many cases it is difficult to see the advance in technology and innovation.

Although there is some truth in the previous assertion, it should also be borne in mind that, on numerous occasions, issues dealt with as innovative activities, which is how they reach the company, have no direct bearing on the project or on construction, since it is difficult to transmit the project results and those of their application to project tasks.

Recently, this perception has changed significantly due to the fact that R&D&I programs are being decisively invested in, in order to bring about improvements in efficiency, productivity and safety in the sector, and above all, in the search for alternatives which enable improved use of natural resources.

- Innovation in Management issues and transmission of technical knowledge.
- Collaborative and new Project management.
- Development of new technologies for a Workplace healthy and safe.
- Development and improve Construction process simulation.
- Sustainable site and its surroundings.
- New technologies applied to Installations auxiliary to the site.
- Introduction of information and communication technologies at all levels of the construction process and of the life cycle of structures.
- Introduction of more human sciences to develop new business models based on customer focus, to develop human-oriented innovative construction processes.
Research in new Contracting: subcontractors and suppliers, the whole supply chain.
Research in Risk assessment and monitoring new technologies
New Relations within the company, and other bodies associated with construction projects the role of technology.
Research and technology in Design and management of intermediate stages, processes and evolving structures.
3. Europe 2030: A vision for the Future of Construction

The long-term prospective on research needs that set ambitious objectives to the sector is the vision of:

**Challenging and Changing the Built Environment of Europe**

A vision for a sustainable and competitive construction sector by 2030

"In the year 2030, Europe's built environment is designed, built and maintained by a successful knowledge – and demand – driven sector, well known for its ability to satisfy all the needs of its clients and society, providing a high quality of life and demonstrating its long-term responsibility to the mankind’s environment. Diversity in age, ability and culture is embraced. Equalisation of opportunities for all is an overarching principle; construction has a good reputation as an attractive sector to work in, is deeply involved in research and development, and whose companies are well known for their competitiveness on the local and regional as well as global levels."

The aim of the vision for the Future of Underground Construction is to let free above ground space for the use of the citizens, taking the infrastructures underground. Employing the largely available underground space for the harmonious development of the population instead of the traditional construction model of developing cities in elevation and horizontally.

In order to reach this vision, the underground construction has to be efficient, safe, with a complete social acceptance and with a minimum impact on the environment. Objectives and typical research targets had been summarised in two key aspects involving these main challenges of underground construction: *Meeting client requirements* and *Reaching sustainability*.
Meeting Client Requirements

Europe provides a variety of attractive, healthy, safe, accessible, useable and sustainable environments in which a diversity of social and cultural values are welcomed and fostered; places where significant economic prosperity is underpinned by social cohesion.

Advanced techniques and know-how for urban design and building enhance the competitiveness of the European construction industry. The construction sector is based on client- and user-driven complete life-cycle processes. Cost reduction of the overall value chain results in increased competitiveness, new business opportunities, new investments and in economically viable services to the largest possible client base. Optimal allocation of available economic resources is met.

New research focuses on how technology can address human sciences and socioeconomics, and how the sector can profit from exploring the current design gap. Inclusion of diversity and the equalisation of opportunities for all are overarching principles that strengthen the sector by enabling it to reach new users and make contacts in many different communities. The design in the construction sector is recognised by the public as indispensable to development of the built environment.

Becoming Sustainable

Europe combines ‘high tech’ with ‘high culture’, and is a natural leader in creating a sustainable built environment. The built environment links nature and citizens in a sustainable way. The built indoor environment enables health and comfort in living, moving and working. The negative impacts of construction’s whole life-cycle on the environment are radically reduced, thereby substantially improving the sustainability of the construction sector in Europe, with policies such as aiming for zero-waste construction and an efficient use of all resources. Environmental life-cycle approaches are adopted for design, construction works, maintenance and operation, as well as product development.

Besides these two major objectives, the Vision 2030 document introduces another objective for research: Industry Transformation. New materials, technologies and services are necessary to reach the objectives of Meeting Client Requirements and Becoming Sustainable.
**Transformation of the Construction Sector**

Society is the client and the end-user of the Construction Sector; it is the main driver for change of the construction process.

Cities, buildings, are built, and technologies are developed with human behaviour and needs constantly in mind. A high level of technology is supported by a comprehensive knowledge base which is shared throughout the value chain, from the client to the rank and file site worker. Quality of the construction is continuously assessed and tracked throughout a transparent process.

The Construction Sector conveys a new image of innovation; it creates new business opportunities and offers good working conditions to all.

3.1 Rationale and challenges

The traditional construction model is to develop cities in elevation and horizontally: ever higher buildings, ever sprawling across the countryside. On the opposite, underground space is largely available: it must be employed now to provide congested European cities with the space they need for their harmonious development.

The social, environmental and economic issues that are reflecting the immediate and long-term problems and opportunities in Europe’s Built environment can be faced on the underground construction sector. The creation of underground space has significant impact on quality of life, working conditions, the employment and the environment. Innovative use of underground space will have a great impact. European Union policies include an upgrading of the Trans European road network (TREN), in order to improve interstate transport. This implies the construction of a significant number of tunnels (approx. 2100 km of tunnels will have to be constructed in Europe by the year 2030).
The Waterway, Rail, Air and Road Networks will constitute the main arteries of our society for the transport of people and goods. But none of these transport networks will be sufficient to fulfill by itself the transport requirements and optimal solutions will involve two or sometimes three transportation modes. Therefore, efficient links between these main arteries, the so-called intermodal transport network, will constitute key elements for the overall efficiency of the networks.

The infrastructures for such intermodal transport networks will most of the time be located in densely populated sub-urban areas. In order to preserve the quality of life and the cultural heritage in these areas it will be necessary to locate these structures as much as possible beneath the ground level.

Furthermore, with the strong desire to improve the quality of life in the European Cities of 2030, it will be necessary to mitigate as much as possible the influence of all activities or infrastructures which have nowadays negative impacts. Industrial activities, like incineration or power plants, which cause visual or olfactory hinder, main roads or railways, which cause harmful noise, vibrations or habitat fragmentation, shall preferably be placed under the ground.

Many existing transport underground infrastructures, like metros or railway tunnels from the early 1900, do not comply with today’s health and safety requirements, have insufficient capacities or limited service life and these structures have to be upgraded.

Water companies and other public utilities (gas, electricity, telecommunications, etc.) are continuously, but independently one from each other, upgrading and repairing their buried infrastructures. The socio-economic cost of traffic congestion due to such maintenance works road works is enormous. New technologies have to be developed to achieve common buried infrastructures, shared by the different users/suppliers, with the aim to improve operation, maintenance, rehabilitation, serviceability, pollution prevention and safety.

A steadily increasing market value of the land property in the cities will constitute another important driving force to better exploit the underground space, which is today still widely underused compared to the space at ground level.
If Underground technologies are fully developed to their implicit potential the cities, natural obstacles like rivers, mountain ranges, and forests will not be obstacles any more the natural alternative will be to by-pass them underground; this solution could be applied in the future to protect sensitive natural environments and to avoid land rights acquisition to implement new transport infrastructures.

Underground construction operates in a very competitive international environment. For example, countries such as Korea and Japan have long learned from European experience and are investing significant research funds in innovative technology, in order to take a leading role in the world. If the European industry sits back and allows this to happen, then its competitiveness will be lost and the economic damage would be substantial. European construction will only have a real chance of being competitive, if we gather all available research clusters in Europe and create a critical mass in order to achieve a breakthrough in the application of innovative technology.

The use of underground space will significantly contribute to resolve societal and ecological problems in the future. The main concept could be: to colonize the underground space in urban area (more than 80% of the population lives in cities) and the ways to link these areas, in order to develop a friendly environmental and societal space at ground level.

In cases where the coastal shoreline is already cramped with constructions and developments, thanks to the development of safe and fast underground connections we can establish off-shore facilities and developments with underground links to the mainland, this will help to create new land developments for housing, commercial or industrial use.

The development of the underground works specially long tunnels (more than 100 km) with reasonable costs and improved safety will help the implementation of new transport technologies like the MAGLEV (magnetic levitation vehicles) for speeds up 600 and 1000 km/h in the next decades.

High speed transport systems like the MAGLEV need a heavy investment infrastructure above ground for its sole use, in this case and similar ones with the improvement of the efficiency of underground excavation costs, the underground solution would be a very convenient one to alleviate above ground pressure, decrease impact and increase efficiency.

Long range tunnels linking main cities would be a very efficient solution to establish a high speed grid among European centres.
Ground excavation technologies are divided today mainly in two fields NATM where the surrounding ground collaborate with the support of the excavated ground and the TBM or full section excavation where the support is applied through the concrete segments of the lining with little or none use of the surrounding ground for support. It could be expected to find out a new line of development of TBM equipment able to interact in deep with the surrounding ground through spikes, anchorages, injections included in the machine cycle, to alleviate the support through segments thickness and strength.

The expected increase in tunnel diameter for the next decades could be accelerated if the surrounding ground once treated collaborates to the tunnel support and helps to ease the size and thickness of segments and to the stability of the whole section.

The experiments carried out in Japan in the last decades for non-circular shapes of full face excavation or TBM’s with a square, rectangular or ellipsoidal cross section have not been successful 100% but with the development of new improved robotized operations, ground support and new materials for improved lining we can expect that this type of machines will be fully developed in the coming years for larger sections.

To alleviate the costs of larger TBM’s we can expect the development of non-full face excavation equipment of new generation like improved roadheaders similar to partial section TBM’s working in a shielded environment like some soft ground experiences already in the market.

We have to considerer the underground works as a collaborator in the development of new energy sources, geothermal energy for example will benefit in its economical feasibility in a lot of places with the development of underground technologies.

The storage and elimination of dangerous waste could be accomplished with high energy solutions like plasma disintegration and underground storage facilities all the process could be automatized or robotized without workers intervention and monitored from the surface and the inert material produced used to fill caverns or other non-usable underground spaces.

![Double shield Pajares tunnel d=10,12 m](image-url)
Personnel training will need to be developed with a new generation of simulation tools, increased reality and virtual reality tools, the sophisticated equipment of the future will need the development of simulators for operators, new multilingual, multicultural tools and exchange of experiences on-line across Europe.

Databases for tunnel experiences will be available and the learning curve and problem solving capability of the European companies will increase dramatically with the implementation of this Technological Platform and the associated initiatives.

3.2 Vision 2030
The Vision 2030 for the Underground construction is as follows

“Our aim is to let free above ground space for the use of the citizens, taking the infrastructures underground.

In order to do that, Underground Construction will be efficient, safe, with a complete social acceptance and with a minimum impact on the environment.”

In order to reach this vision, objectives and typical research targets are specified in the following pages for four key aspects of construction:

Main Challenges:

- Increased efficiency
- Improved safety
- Minimum impact on the environment
- Complete social acceptance

To achieve these challenges the underground built facilities must be safe, sustainable, with minimum impact on the environment and competitive when compared to above ground solutions. New construction concepts must be invented to support this radically new model proposed for the development of cities:
Cities extend downwards in an unlimited ground space, limited only by the borders of technology and imagination;

A human-friendly underground infrastructure is closely interconnected to a surface living space with a better environment;

Underground cities are linked together or to the airports by high velocity and high capacity transportation lines for passengers and freight, offering an efficient alternative to road transport.

A whole new concept of underground construction is needed: the whole supply chain must be reviewed to cope with the constraints of an enclosed space - new contractual arrangements for a new world, new services industries to work underground, new underground architecture, new specialised vehicles; new technologies for excavation, new social business, new concepts for the safety and security industry, for the supervising and protection, for hazards and risks mitigation.

### 3.3 Increased efficiency

The efficiency of Underground construction will be increased by the development of new equipment, techniques, tools, processes and materials. These advantages will be visible as products of research that will give birth the European future infrastructures and life style. The evolution will follow different stages along the new future; the achieved goals are going to be:

**Long term (vision 2030)**

- **A similar cost for underground and above ground infrastructures:** The optimisation of the excavation procedure and the complete avoidance of unexpected ground behaviour will allow an important reduction of the actual costs.

- **A complete knowledge of underground utilities behaviour:** The use of intelligent systems during whole life cycle will give the adequate information about the behaviour of the infrastructures, allowing the actions that could be needed to take preventive or corrective actions before the potential problems will grow.

- **Great artificial caverns:** Built with accuracy and safety with smart lining systems and monitoring mechanisms to allow large infrastructures to be underground.

Swimming pool placed underground - Finland
Strategic Research Agenda & Vision 2030

- **New material developed for underground lining** with smart properties to monitor and assess the integrity of the underground facilities.

- **Ground disintegration excavation technologies** in an experimental phase developed thanks to new energy sources developed.

- **Ground change of properties through external energy actions** like electrocoagulation or others developed.

- **Reduce the cost of underground works by 50%**: to achieve this, full knowledge of the terrain and efficient processes and equipment must be carried out.

**Medium term (vision 2020)**

- **Universal tunnel boring machine (TBM)**: The development of TBM’s capable to work in any type of ground without stopping will be an important element in order to increase the efficiency.

- **A complete knowledge of geological conditions (“transparent ground”)**: The development of innovative methods and equipment for geological exploration will allow speeding up the process of excavation, reducing stops in the work.

- **A breakthrough in rock cutting technology**: Important advances are expected in new cutting technology (e.g. laser technology), which will imply less problem during excavation.

![TBM with cutting discs for hard rocks](image)

- **New generation of self guided drilling jumbos fully robotized and without any person inside**: Development of efficient drilling bits, and other wear pieces.

- **New generation of installations equipment for underground construction**: New efficient locomotives, power packs, maintenance and service vehicles without interference with the construction activities

- **Directional drilling technologies for horizontal and vertical boreholes** for up to 2000m with precision to obtain samples and ground analysis without core extraction.

- **Sensors embedded in the ground** with data transmission capability and long life
Ground penetration radar with capability to reach several hundred’s of meters to obtain geotechnical data.

Development or flexible lining for tunnels, with capability to absorb settlements and ground movements without losing water tightness and bearing capacity.

Excavation or large diameter caverns incorporation of all types of rocks included loose soils.

Development of the technology of reinforced soil surrounding TBM excavation area

Development of communication transmission systems through the ground environment.

Shaft deepening equipment with similar efficiency for vertical and horizontal excavation and all the inclined grades.

Development of robotized vertical jumbo drilling equipment for shafts.

Development of electric driven hammers with electronic high frequency or other types of excitation and motors.

Short term (vision 2010)

Intelligent lining systems: Development of new linings with auto-correction depending on ground actions will allow a better knowledge of underground infrastructures behaviour.

Cost efficient large diameter tunnels: Important development of new tunnel boring machines for large tunnel cross-section will be produced, also in cutting technology.

Self learning equipment: New equipment capable of making automatic modifications from the data collected during construction.

TBM’s for non circular sections: New developments for effective square, rectangular or elliptic shapes.

Robotized operations inside underground works: Some of the operations will be fully automatic

Accurate Forecast for ground movements and interference with existing facilities: Development of a new generation of prediction tools, sensors and other instruments with the analysis capabilities to take decisions in advance for the surrounding ground response.

Simulation for ground characterization 3D and 4D: to allow precise prediction of ground behaviour.

Immediate flexible support systems: to allow a wide range of loads variation

Long life drilling bits, rods and other consumables: to allow drilling capacities without changes of bits or sharpening for 2000 meters.

Self positioning and self operation for fully robotized drilling jumbos, explosive loading and mucking operations.
3.4 Improved safety

The safety of Underground construction will be improved in order to achieve the two mainly important goals: no-workers inside tunnel and zero accidents. Therefore the following developments to achieve:

**Long term (vision 2030)**

- **No workers inside tunnel during construction:**
  
  This achievement will be possible by the development of totally automated remotely controlled tunnel construction work. In order to do that, new equipment, techniques, processes and tools shall be produced.

**Medium term (vision 2020)**

- **Increased safety in the use of TBM’s:**
- **The development of new tools and systems in the design of TBM’s will benefit the workers, decreasing the possibility of accidents.**
- **A complete knowledge of geological conditions (“transparent ground”):**
- **This will decrease the possibility of accidents, due to the fact that the necessary previsions could be taken in advance. These accidents are related with workers and also with the general society.**
- **Development of new systems for safety immediate support of soil and rocks: smart solutions for immediate safety.**
- **New generation of explosives materials without fumes and totally insensible to accidental blasting**
- **Mix design for segments with anchorages to the surrounding ground: mixed types of support and lining.**

Inside de TBM machine - Madrid underground works
Short term (vision 2010)

- Increased automation of machines:
- The development of new automated machines will increase the safety of the workers, because their work will be less dangerous.
- Improvements for the indoor environment for underground works, substantial comfort improvements for the workers and users.
- Automatic changes for rollers and cutters: without participation of workers

3.5 Minimum impact on the environment

The impact on the environment of Underground construction will be minimised by the following developments

Long term (vision 2030)

- Complete waste reuse:
  All the waste produced, as a consequence of underground construction works, will be reused. The excavation materials will used to produce new materials to be used in the underground constructions or in other applications.
- Minimum pollution (air and water):
  The pollution of any type (mainly on the air or in the water) will be minimised to a level that could be allowed, taking into account parameters of very low contamination.
- Development of tunnels for great lengths of more than 100 km without any intermediate portals and without any relevant connection with the surface
- Development of geothermal massive energy: with the help for very deep tunnelling and drilling technology

Medium term (vision 2020)

- Avoidance of any impact in the water (no waste disposal, ph neutralisation, natural drainage….):
  Some measures will developed in order have more care in order to decrease water contamination.
- Adequate waste management and recycling:
- Valorisation and recycling will be a normal practice regarding the waste produced during underground construction works.
- High speed links among cities through tunnels to carry high speed lines below ground surface with safety and without noise or contamination.
- Submersed tunnels to link coastal cities, (Ponte di Archimede – Professor Perotti) or development facilities through submersed tunnels anchored to the sea bottom for several transport systems or facilities tunnels.
Development of recycling systems for the excavated material through plasma technologies and ultra compaction with molecular changes.

Solution to environmental problems through the use of underground facilities, waste storage, treatment plants, noisy installations, containment of pollutants, etc.

Supply of construction materials through underground works thanks to the decrease in excavation costs, quarry and borrow pits will be underground and the voids generated will have an economical value.

Recycling of the obsolete underground tunnels as containers for waste filling materials.

Landscape correction with materials excavated or incorporated to underground workers.

Development of new urban soil barriers for correction of noise and visual impact with materials extracted from underground facilities and at the same time gain space in underground for city installations.

Short term (vision 2010)

Minimum affection to the faunae & vegetation:

The minimisation of the affected area by the works will be achieved. Also, replanting vegetation of degraded areas and use of local species will be practised.

Low noise level production:

The use of weight vehicles only during certain hours and traffic planning will be used normally. Also, low noise production blasting techniques will be applied.

Extruded concrete for lining with materials obtained from the excavated material, and treated inside the tunnel

Full development of clean foam and additive agents incorporated in the excavation process with near 100% recycling and no consequences for the environment.

Back filling of the tunnel concrete segments with the excavated material treated inside the tunnel.

3.6 Complete social acceptance

The acceptance by the Society of Underground construction will be obtained by the following developments

Long term (vision 2030)

Comfortable underground utilities and infrastructures:

The improved use of underground facilities and infrastructures will completely accepted by the citizens through the implementation of measures related with accessibility and comfort ability.
Social penalization for the use of surface ground area for facilities with significant taxation charges, and social and economical surcharges for the use of open spaces above ground. Revaluation of the spaces and market for the new multi-dimensional space with total social acceptance.

Experimental nuclear fission plants for power supply of underground works

Medium term (vision 2020)

Adequate access at existing utilities:

The implementation of adapted access, at existing utilities, for disabled people will allow the use of these facilities to these citizens that today have important barriers to use those.

Plan easy access when designing new infrastructures (no arquitectonic barriers):

The use of these ideas in the development of new designs of underground facilities and infrastructures will obtain the same effect than the previous improvement.

Real Estate market for underground facilities economical surface or volume

Development of industries and services based in underground facilities location.

Fire fighting devices and security equipment able to handle incidents in the first seconds of detection with punctual an precise action where and when required.

Thermal imaging and long range sensors to avoid incidents in underground works, continuous molecular analysis of air, effluents, etc. for improved monitoring.

Robotized vehicles for maintenance and service of tunnels with automatic tasks and predicted behaviour.

Recycled for old tunnels and underground facilities for second class uses (storage, dumping area, etc.) alternative uses development.
Short term (vision 2010)

- Less barriers for disabled people:
  The development of standards where requirements for all new designs include
  the obligation of decrease or eliminate the barriers for disable people will be
  produced.
- Development of tunnel links directly to the underground transport systems and
  city facilities.
- Harmonization of standards and codes for underground works.
- Smart detection of fire incidents in tunnels with sensors able to detect fire
  incidents in first minute.

3.7 Generating and implementing R&D and Innovation

The process of construction itself is one of problem solving, though traditionally, change
has been local and incremental. Barriers to groundbreaking innovation in construction
include:

- The number and range of interests involved in a construction project.
- The complexity of construction outputs.
- The lack of performance-based competition.
- A focus on initial costs.
- Short-term relationships.
- The high proportion of small firms.
- Lack of adequate skills and training.
- The long-term consequences of failures.
- Regulations and standards.

These are significant barriers, and efforts to reduce them piecemeal will likely fail.
The framework for collaboration within R&D must therefore take as its point of origin the
development of the sector as a whole, by bringing the individual project problem-solving
approach to a more universal, sector-wide application. This includes the creation of a
positive innovation climate and strong, coherent innovation processes (including
infrastructure, education and training), radically enhancing the number and quality of
new products, processes and services being introduced.

A construction sector open to innovation would have the following characteristics:

- Long-term relationships both within the supply side and between supply and
  client interests.
- A focus on performance and costs over the life-cycle and away from initial costs.
- Knowledge-based, with people at all levels able to assess and implement new
  concepts.
- Widely accepted sets of performance indicators.
- A network of information and knowledge services.

This is the innovation context in which R&D will facilitate the transformation of the
construction process. This change will necessarily be driven by the sector itself and
supported by authorities.

In addition, next to the influence of research, it is important to recognise the
mechanisms behind other sources of innovation in construction: product supplier
initiatives, the influence of parallel industry sectors, individual creativity and the actions of operators and users.

In sum, the responsibility for developing our sector lies with all stakeholders. The way that clients articulate their requirements, specify and commission their projects is pivotal to the ability of the sector to produce and implement innovation while ensuring overall quality and sustainability. Clients’ focus and dialogue with the other parts of the sector will set the objectives.

3.8 Closing remarks

The challenges that underground construction is facing are its opportunities. The engagement of the design and construction sector is essential to achieving a sustainable and competitive Europe. The built environment is an amalgam of environmental, economic and social issues, reflecting everyday and long-term problems and opportunities for the people of Europe. The development of the sector needs to take this cross-disciplinary character into account.

Preparing to meet the issues at hand requires a careful critical analysis of the construction process from both a builder’s and a user’s perspective. Changes will be, of necessity, evolutionary, incremental and gradual procedures. A new Europe is growing with the accession of many new countries; this provides a unique opportunity to introduce a new approach to underground construction and to develop our sector into the competitive, responsible, knowledge-based and client-driven builders of the new Europe.

There are no straightforward instantaneous solutions. We must approach an understanding of clients, societies and environments. On behalf of the sector, we summon all involved in European design and construction to contribute to this new vision for the built environment.
4. Strategic Research Priorities

The underground construction is a huge industrial sector, which involves the most of the general construction enterprises. The most extensive amount of these industries are concerned in the underground extension development to unify forces in order to advance in all processes involved. Furthermore, the dimensions of the social demand are multiple, which makes the selection of a coherent set of priorities quite a difficult task. Table 1 below gives the list which is proposed by the focused area in underground construction of the ETCP.

Planned concepts for the new research

- Concept of multidimensional design for the city and its environment
- Technologies to build spaces in any size and in any ground, anywhere
- Three-dimensional architecture and integrated planning
- Specific new ultra-fast transport systems
- Full knowledge of the ground, the transparent soil.
- Development of energy issues from soil, and its capacity for storage, generation, regulation.
- New generation of tailor made and smart materials for construction.
- Research for new sustainable friendly construction processes with no impact, safe and healthy
- Integrated management over the whole period of working life of infrastructures
- Removal of barriers of all kinds and service brought closer to the public
- New concepts for urban planning for utilities and services, integrated approach.

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TABLE 1: Priorities for the new research
4.1. Meeting Client Requirements

4.1.1. Efficient use of underground city space

4.1.1.1 State of the Art

Congested European cities need always more space for their harmonious development. The traditional construction model is to develop cities in elevation and horizontally: ever higher buildings, ever sprawling across the countryside. On the other hand, underground space is largely available: it must be employed now to provide congested European cities with the space they need for their harmonious development. To address this challenge the underground built facilities must be safe, sustainable, with minimum impact on the environment and economically competitive against above ground solutions.

4.1.1.2 Objectives

New construction concepts must be invented to support this radically new model proposed for the development of cities, whereby sustainable cities extend downwards in an unlimited ground space, limited only by the borders of technology and imagination:

- Underground space is designed for all and accessible for all, has the same level of comfort, safety and security as surface space, and is closely interconnected to surface living space.
- Affordable and competitive new underground space relieves congestion at the surface and integrates facilities and economic activities which are today dispersed in cities.
- Underground space contributes to the protection of environment and of Cultural Heritage.
- Underground space contributes to the energetic balance and to the development of new energy sources.
- Underground cities are linked together or to the airports by high velocity and high capacity transportation lines for passengers and freight, offering an efficient alternative to road surface transport.

4.1.1.3 Research Areas

Short–term

- Social and Human relations for a new environment; developing psychological and social acceptance of the underground environment;
- Improved understanding of human behaviour for long periods below the surface, to adapt the minds to 3D movements in a vertical city, instead of 2D movements in today’s horizontal cities.
- Development of new standards and codes for the new environment.
- Architectural design for the unlimited conquest of deep available space, playing with voids, filling spaces and caverns with new inverted concepts of buildings, interacting with surface buildings, human-friendly and designed for all;

Medium–term

- New materials for waterproof and self-caulking, insulation, fire safety, strong enough to withstand ground pressures, flexible enough to absorb ground movements and with high durability in underground environment;
Construction Processes for large underground spaces below cities and interurban connections:

- New tunnelling technologies: long tunnels, air-tight lining, specific materials;
- ICT controlled, fully automated excavation procedures with low impact and flexible equipment, for any size and shapes of excavations;
- Fibre ground support with re-absorption, modular and flexible ground anchors, sustainable grouting, and lining;
- New techniques for ground treatment, recycling of materials;
- Ground conditioning special devices, ventilation, air regeneration and conditioning, exhaust absorption, communications, transport systems, ground water treatment.

Long-term

- New concepts for the comfort of underground spaces: air-conditioning, artificial sun, etc;
- Perfect knowledge of surrounding soil condition and its evolution along the life cycle of the projects;
- Life cycle assessment of underground structures under existing premises;
- Development of new standards and codes for the new environment.

4.1.2. Knowledge of the ground

4.1.2.1 State of the Art

As described previously as a general client requirement, underground construction provides a powerful solution for the ever growing claims on free space in our (build) environment. On one hand today’s society asks for more mobility of people and goods, resulting in a continuous demand for new or upgraded infrastructures. One the other hand society puts stern demands on the quality of the living environment. By development of several promising techniques / processes related to underground construction the subsurface is to be exploited as a huge space, waiting to be founded, where all services that are unwanted at the surface can be located.
It’s remarkable that budgets for soil investigation are approximately 1% of the actual costs for realization. Furthermore corresponding foundations amount 3 to 10 % of the total investment for the realization of constructions. Cases where aberrant behaviour of the underground / subsoil lead to an increase of these costs up to 10, 20, 50 or even 100% are not uncommon. Innovations resulting in a better understanding of the underground will therefore have a drastic effect on savings and risk reduction for all construction projects, especially underground construction projects.

Within underground construction uncertainties are encountered. Most of these uncertainties are related to the underground. Within construction in, on or with soil ranges of uncertainty nowadays of up to 50% are not unusual. The aspect of the subsoil contributes considerably to high annually efficiency losses and costs of failure in construction. Speeding up innovation in the field of geosciences / -engineering will result in reduction of ranges of uncertainty and increase of reliability of predictions and will have an enormous positive effect on society. They will lead to lower costs for clients (often public organisations) and higher benefits for construction (related) companies.

However trivial it may seem, with underground construction the underground (or subsoil) becomes an integral part of the actual construction, more than in construction above ground. One might actually state that soil becomes a construction material crucial / essential for the behaviour of underground constructions. From this point of view modification of actual soil conditions by treatment of any kind will also be of great importance to the successful construction, operation and maintenance of underground constructions.

4.1.2.2 Objectives

The general goal is the overall decrease of efficiency losses and costs of failure during construction through grasping the actual subsoil and understanding and controlling its behaviour.

Understanding the underground in a practical sense (i.e. what actual soil types does one encounter when going underground?) as well as in a more theoretical / fundamental sense (i.e. how does the encountered soil types behave, what are its crucial parameters, can one predict and/or monitor its behavior?) is therefore very essential.

The aim is obtain a “transparent ground”, knowing exactly the geomechanic characteristics of the terrain and the crucial parameters that will allow us to model and predict its behaviour through sensor perception and numerical simulation.
4.1.2.3 Research Areas

‘Grasping the Underground’

- New methods and techniques for creation of a continuous image of the underground by soil investigation and monitoring
- New methods and techniques for detection of obstacles during construction by soil investigation
- Reduction of ranges of uncertainty regarding soil parameters through laboratory testing

‘The Underground Understood & Controlled’

- Increase of reliability of predictions regarding the subsoil behaviour by measurements and monitoring
- Validation of subsoil modelling by advanced multi-scaling techniques, varying from geocentrifuge testing to real-size testing
- Full knowledge of geological conditions (“transparent ground”): development of new methods and equipment for geological research to reduce downtime during construction
4.2. Becoming Sustainable

4.2.1. Reduce Resource Consumption (energy, water, materials)

4.2.1.1 State of the Art

Tunnels and all underground spaces in general require the use of large-scale ventilation systems, which are a major cost factor in comparison to surface work, both in terms of initial investment and operational costs. In contrast, underground structures are very well-insulated against the elements; this considerably reduces air conditioning costs and is in fact one of the prime motivational factors behind many underground constructions. However, it is not possible to make the most of renewable energies such as solar, which will be a prime consideration for building above ground in the near future.

In general, underground construction work requires very high energy consumption, with it being necessary to reduce this by using low consumption equipment and new energy recovery and generation systems through the use of marginal products.

It will finally be necessary to take into consideration one of the main agents involved in underground construction work, as well as all the planet's biological and mechanical processes: water. The management of this agent is a vital aspect, contributing to a major improvement in consumption and the overall sustainability of the construction work.

4.2.1.2 Objectives

☞ Energy

The design criteria of these systems need to be reviewed in order to optimise their dimensioning and guarantee their ability to respond adequately to emergency situations. The design of the equipment which makes up these systems must also be improved, making it more efficient and environmentally friendly.

With regard to air-conditioning of underground spaces, many of the advantages that the ground can provide are yet to be exploited, especially below a certain depth. The possibilities of exploiting low enthalpy geothermal energy by means of drilling carried out from underground structures or the thermal inertia of the ground itself as an accumulator and control element in air conditioning systems, developing simple and efficient solutions, must be analysed.

☞ Efficient and Environmentally Friendly processes to minimize resource consumption

In order to minimise the use of resources that require the processes carried out in underground construction, a comprehensive construction work management system needs to be developed. This will enable data collection and analysis at every project stage, from design through to operation, maintenance and execution, and allow real-time diagnosis of existing pathologies, facilitating their solution.

This must be complemented at the same time by an auxiliary works management system, which focuses primarily on service and traffic diversions in order to minimise their impact on areas in the vicinity of the work site.

Once the most ideal sectors for minimising have been located, it will be necessary to develop low-energy consumption equipment and systems which enable energy...
recovery and generation, optimising and reducing energy use during the execution process of the construction project.

A system that enables control of the disturbances produced by the underground construction work in the surrounding area and that facilitates the solution of these disturbances before they occur will be necessary too.

*Water management issues in the underground facilities.*

Efficient water management in underground building work is closely linked to the development and adaptation of technologies for reusing and recycling wastewater, the development and demonstration of pressure exchange technologies for application at different depths and the development of tools for evaluating underground water resources in order to obtain maximum efficiency and viability in the use of underground channels.

4.2.1.3 New knowledge generated

*Optimization in the energetic consumption and acclimatization services*

- Use of the low enthalpy geothermic energy.
- Improved efficiency of the equipment, fans, excavation and transportation machinery, etc.

*Energetic balance and optimisation of the construction process*

- Energetic analysis of the processes
- New developed equipment of low energy consumption
- Energy recovery system
- Advantage and use of marginal heat generated.
- Development of alternative equipment for energy generation
4.2.1.4 Developed innovation and indicators

- Development of new equipment based in low energy consumption to be used in the jobsite for construction purposes.
- New systems for energy recovery in underground Works.

4.2.2. Reduce Environmental and Anthropogenic Impacts

Strengthen actions for environmental conservation and improvement

4.2.2.1 State of the Art

From a biological point of view, the city is an ecosystem with very low productivity compared to its extremely high consumption and dependency on the environment. For a city's human requirements, it is necessary to extract materials from the environment (agricultural, mineral etc) and import energy which, after use, is exported as waste that will have to be absorbed by the surrounding environment (sewage, rubbish, atmospheric pollutants).

While carrying out services in the city, this consumption of the environment’s raw materials increases along with the provision of materials from the excavation. Every underground work produces major changes in the environment, soil conditions, groundwater and the immediate surrounding area. Factors such as soil movements or vibrations and changes in the surrounding soil conditions are added to aspects that cause anthropogenic changes in the environment. The aim nowadays is to find solutions for:

- Fining pollution
- Aim to deal with existing pollution
- Changing ground conditions
- Soft soil conditions
- Vibrations and acoustic emission
- Excavated materials
- Irreversible situation
- Ground water
- Ground movement (settlement surrounding)

These issues have to be tackled in the future upon the speed of development of the technology required to solve them and the evolution of the problems and their incidence.

4.2.2.2 Objectives

Short- term

♫ Minimal impact on wildlife: minimising the areas affected by the building work; landscaping of degraded areas using native plant species
♫ Reduction of noise pollution: by limiting the use of heavy vehicles and planning traffic. Minimising noise and traffic around sites

Medium- term

♫ Reduction of impact on water: elimination the dumping of liquid pollutants, pH neutralisation, natural drainage.
Strategic Research Agenda & Vision 2030

- Appropriate dumping and recycling procedures: recycling will be a standard practice for the treatment of excavated materials, treatment of 100% of extracted products
- Expert revision system
- Recycle materials

**Long-term**

- Waste fully reused: all waste produced by underground building work to be reused. Excavated materials used to produce new materials.
- Minimal pollution (of the air and water): all types of pollution to be reduced to admissible levels, according to stringent low-pollution parameters
- Development of very long tunnels (over 100 Km): with no intermediate access points and insignificant connections with the surface
- Zero environmental impact
- Virtual construction fully integrated
- Control of risks
- Minimum vibration
- Full reuse of excavated material
- No pollution in the inside construction and operation, and outside of the tunnel

![Parking under Santa Teresa Square – Ávila (Spain)](image)

**4.2.2.3 New knowledge generated**

**Short-term**

- Treatment areas assessed efficiently
- Quiet, compact equipment and processes

**Medium-term**

- Degradable materials; correction processes
- Treatment processes for materials, fluids and gases

**Long-term**

- Recycling, new applications
- Distant work faces with safe, efficient resources
4.2.2.4 Developed innovation and indicators

**Short-term**

- Detailed knowledge of impact and remedies
- Quiet, combined transport; Partial recycling; Redesign of processes

**Medium-term**

- New chemical agents; Clean processes
- Newly designed products and equipment
  Indicator: Percentage of pollutants elimination (90%)

**Long-term**

- Flexible recycling equipment; Terrain compatible materials
- Self-contained internal processes
  **Indicators:** Percentage of pollutants (50%), Excavation length per month (double speed for similar conditions of the ground).

4.2.3. Improve Safety and Security

Achieve optimal health and safety levels for all building processes

4.2.3.1 State of the Art

There are some important reasons for adequate security and safety aspects in the underground construction. There are a great amount of people with the demand of feeling safe and secure. Actually safety is something that have to be completely solved in the next generation of the construction. No accidents is one of the most important priorities, and it has to be, because it is highly complex in an underground environment, the ground is sensitive and vulnerable regarding breakdowns, incidents and damages.

At the same time, the sector has to focus in security too, taking in account that infrastructures are attractive for potential terror attacks. Prevention of vandalism, terror attacks (see Madrid, London) and crime gets more and more important. Usually there are complex independences of incidents, safety precautions measures and effects between different parts of the underground constructions. It is needed a spread out of problems. Underground facilities may include processes which are preferably to be put underground in future (power production, productions with emission of noise, transport of goods, waste disposal, supply of merchandise). Hiding of these activities underground will present a challenge with respect to safety/security. Future use and possible changes in future use can change safety and security requirements.

Several other motivations are at the present time topics in this field:

- Efficient and user friendly interfaces between underground facility (e.g. production, offices, shopping) and transport system versus safety and security measures.
- The future amount of people demands new evacuation concepts (Rescue to the surface, underground rescue shelters, ...)
- Projects have complex planning activities and neighbour systems have to be coordinated
• Multidimensional complex construction process requires a care planning of construction procedures and the risks involved
• The underground structures, the materials and the operational concepts will have to withstand all relevant hazards (natural hazards, sabotage, terror, accidents ...).
• The operation of the facilities will have to be energy-efficient.
• Public opinion about „visionary“ underground projects can play an important role.
• Security and safety requirements have to be quite high.
• Risk acceptance criteria have to be considered carefully.

4.2.3.2 Objectives

Two main lines for the approach to the objectives will be followed:

**Approach for “Safety and Security Support Infrastructures”**
Development of an approach and of structural measures for “Safety and Security Support Infrastructures” during operation.

- Concepts of support galleries/caverns in great and complex underground systems for safety and security reasons (arrangements and locations, designs, ...)
- Systems have to serve different uses (people rescue, water or gas retention rooms, propagation of explosion waves, ...)
- Constructional measures (doors, bulkheads, ...)
- An integrated approach to safety and security in the complex, sensitive and vulnerable underground facilities must be aimed at in order to achieve the optimal security and safety in the entire life cycle of the facilities (planning, construction, operation, and deconstruction).
- Every relevant part of underground infrastructures and the interfaces between them have to be considered with respect to security and safety – both as an isolated unit and as part of the entire complex.

Inside de TBM machine - Madrid underground works
Research in Risk assessment and monitoring new technologies

Development of intelligent systems for assessing technical risks and sharing them in innovative solutions regarding construction processes, defect probability commenting and estimation of lifespan of infrastructures and buildings due to construction processes.

- Development of objective systems for commenting on risks inherent in innovative construction solutions
- Research for the Transformation of risks into economic figures to enable evaluation of medium and long-term investment solutions.
- Development of systems for reducing or eliminating technological risks on construction sites.
- Possible measures can have influence to the design, to operational and organisational aspects.
- Operational control and risk management for complex underground facilities and transport systems must be optimised.

The vision planning is divided in different periods of time to locate these objectives:

**Short-term**

- Increased automation of machinery: development of automated machinery to increase the safety of workers by making their jobs less hazardous
- New generation of explosives: smokeless and with no risk of accidental fires
- Improved environments for underground sites: enhancing the feeling of comfort for workers and users
- Access control system
- Detection system
- Intervention concepts

**Medium-term**

- Increased safety in the use of TBMs: development of new systems for the design of TBMs to reduce the risk of accidents in the workplace
- Full knowledge of geological conditions (“transparent soil”): will reduce the risks of accidents by allowing the necessary measures to be taken in advance
- Development of new systems to support soils and rocks quickly and safely
New products and processes to reduce healthy problems of workers and users, less emissions.

**Long-term**

- No workers inside the tunnel during construction work: to be made possible by developing new equipment, techniques and processes to enable different tasks to be remotely controlled
- Same risk as on the surface: prevention, reduce consequences
- No accidents due to technical problems, no fatal consequences
- Quality on the surface and underground are the same

4.2.3.3 New knowledge generated

**Short-term**

- Automation and smokeless explosives
- High quality interior environment and enhanced comfort

**Medium-term**

- New operations, safe systems; total control
- Intelligent, quick-acting supports; terrain interaction

**Long-term**

- Automation and remote control of processes
- Sturdy, reliable robots; knowledge and forecasting
- Less risk for construction and operation processes

4.2.3.4 Developed innovation and indicators

**Short-term**

- Investment versus compliance with environmental conditions in tunnel
  **Indicator:** (Increase in 50%)

**Long-term**

- Number of people in tunnel face
- Percentage of automation/today operations
- Accident rates (ranges to reach near zero accidents in 2030)
  **Indicator:** No people in tunnel face, 100% of automation operations, zero accidents.

4.2.4. Enhance the quality of life

Achieve spaces adapted to the needs of the people’s quality of life

4.2.4.1 State of the Art

The city is the current major challenge. The world's population tends to be concentrated in city centres (60% of the population in 2025) where most business activities are
located. This creates malfunctions, or more specifically a lack of environmental quality or urban life quality.

The city can be considered as an ecosystem (any system with interacting components). The city ecosystem is “dynamic and open” since there is both an incoming and outgoing flow of energy and materials. From a social or population point of view, the city is a highly productive system: it generates information, knowledge, creativity, culture and technology, all of which are outgoing flows exported to other systems.

However this ecosystem is also HUMAN, as a result of which certain intangible, unclassifiable and unquantifiable variables that contribute to “quality of life in the city” will need to be considered. It will also be important to introduce the concept of “quality of space”, making sure those citizens that travel around and use these ecosystems are as unaware as possible of the continuation between the surface and underground. A way of achieving this is reproducing life conditions on the surface.

The concept of quality of life for a city's inhabitants has changed greatly. At the moment a pleasant environment is the most coveted asset, as a result of which the use of public funds in strategic investments is vital to achieve these goals.

4.2.4.2 Objectives

Short-term

- Fewer architectural barriers for disabled people: development of standards to include the obligation to remove barriers from all future designs
- Development of access points using direct connections to underground public transport systems and city services
- Development of regulations for the execution and use of new spaces

Medium-term

- Rapid access to existing infrastructures: execution of access points adapted to the existing infrastructures, facilitating access for all
- Design of adapted access points in future projects
- Development of industries and services based on underground locations for infrastructures

Long-term

- Pleasant, comfortable underground infrastructures: the use of the new infrastructures will be accepted by the public if they are readily accessible and comfortable
- Social penalties for the use of surface areas to install infrastructures: revaluing the surface for people’s enjoyment, continuous upgrading for updating facilities

4.2.4.3 New knowledge generated

Short-term

- Designs with no physical, cultural or language barriers
- Links with other services; integrated regulations
Medium-term

- New transport and access systems
- Industries for the new space; specific energy for underground areas

Long-term

- Accessibility, design and architecture of the space
- Revaluation of spaces

4.2.4.4 Developed innovation and indicators

Short-term

- Mobility, language and culture solutions
- Multi-modal links and regulations

**Indicator**: Elimination of barriers, symbolic language based on ideograms versus words (100% on all signs)

Medium-term

- Ultra-fast, safe means of transport and access points
- New logistics; underground energy systems; underground communications

Long-term

- Access systems; new designs; innovative concepts
- Market for the new multi-dimensional space

**Indicator**: social acceptance (90% of people with no concern with underground facilities), investment in maintenance (300% of 2005 figures for similar facilities)
4.3. Transformation of the Construction Sector

4.3.1. Increase the competitiveness

Achieve a competitive sector in Europe and in the worldwide

4.3.1.1 State of the Art

The underground construction has the negative role of having expensive execution processes compared with other construction areas. Constructing in the surface usually is cheaper and at the same time give the gentle perception of being modelling and adapting the wild nature to the people needs.

Actually the role can be vanished if the competitiveness of the sector is improved. It has to reduce the problems of costs and risks, reduce time it takes to build due to the uncertainties in soil properties and the lack of automation and apply ICT technologies, which are not utilised enough at that moment.

To take advantage in the worldwide and approach closely to the surface construction costs, one of the objectives have to be the development of TBM suitable for variable conditions with large diameters and capable of working almost 100% of the time, the planned targets are told next.

4.3.1.2 Objectives

**Short-term**

- **Smart lining systems**: self-correcting depending on the actions taking place on the terrain
- **Cost-effective large-diameter tunnels**: development of new TBMs for large-diameter tunnels
- **Self-taught machinery**: new equipment to enable automatic modifications to be made automatically based on data compiled during the building work
- **TBM for non-circular sections**: new developments for rectangular, square or elliptical digging
- **Develop the competitiveness and safety of production technologies of DB-method**: development of smart, interactive investigation, design and sensor based monitoring methods
- **Use of robots for certain operations involved in underground works**
- **Accurate forecasting for earth movements and interference with existing structures**: development of sensors and instruments capable of taking decisions according to the response from the terrain

**Medium-term**

- **Universal TBMs**: development of TBMs that can work in any kind of terrain
- **Developing automated and remote controlled production technologies of D&B (drill and blast)-excavation method**
- **Progress in cutting technologies**: e.g., laser-based technologies to reduce problems during digging
- **New generation of self-guided jumbos**: fully automated robots requiring no human operators
- **New generation of auxiliary equipment**: locomotives, maintenance and service vehicles, without interfering with building work
**Microtunneling**

**Navigation**

**Long-term**

- **Similar cost for underground and ground-level infrastructures:** optimised digging processes and full knowledge of the terrain
- **Full knowledge of the behaviour of underground infrastructures:** use of smart monitoring systems over the whole working life of the structure, enabling any problems to be anticipated
- **Large artificial caves:** built with precision and under safe conditions, enabling large infrastructures to be located underground
- **Development of new lining materials:** to enable infrastructures to be monitored and assessed

4.3.1.3 New knowledge generated

**Short-term**

- Develop new robots, modular equipment and more effective engineering designs to excavate large tunnel diameters and non-circular sections.
- Develop and apply reliable sensors and control parameters.
- Generate new efficient algorithms and develop new numerical methods for modelling engineering processes and forecasting the global environment response.

**Medium-term**

- New adaptable digging machinery and auxiliary facilities to reach the quasi-universal equipment.
- Constant monitoring, data correlation and simulation of available land in any area to get the full knowledge of the ground.

**Long-term**

- Detailed forecasts of the behaviour of the ground
- Full knowledge of the ground; efficient processes and equipment

4.3.1.4 Developed innovation and indicators

**Short-term**

- Use of robots; modular equipment; more effective design
- Efficient algorithms and modelling; Reliable sensors and parameters

**Indicators:** Excavation face area (increase 20%); success rate avoiding incidents automatically (25%)

- Construction will be more efficient (40%)
- Processes fully integrated
- TBM for variable ground conditions > ? 15 m
Medium-term

- Large scope cutting systems; Made-to-Measure sections
- Newly ground research methods with constant monitoring

**Indicator:** Number of types of ground addressed (3 types); agreement between ground predicted and encountered one, for deep and shallow tunnels (improvement of 75%).

- Construction will be very efficient (60%)
- Unified standard for ICT (Full interoperability between design systems)
- Introduction of hydrogen fuel cells
- Fully modular excavation equipment

Long-term

- Deep exploration; New equipment; Automated processes
- New materials, shoring, linings and control.

**Indicators:** Embodied energy, project man-hours/m³, excavated/life cycle cost (100% of the goal); Increase of the span of the tunnel over 60m.

- Construction will be much more efficient (Every issues will be completely different than today)
- Innovative cutting technologies
- Fully automated and interactive (ICT based/controlled)
- Full concept of networks (3-D)
4.3.2. A New Client-driven, knowledge-based Construction Process

4.3.2.1 State of the Art

The vision of a client-driven and sustainable construction sector meeting the requirements is based on active construction clients who can manage all relevant demands from owners, society and different customers into briefing and programming. Construction clients with competence to cooperate with owners, customers and society on the one hand and with the sector as a whole on the other hand are a strong driving force for the transformation of the sector.

Concepts such as whole life thinking, lean production, industrialisation, integrated delivery (notably through the development of partnership relationships and of integrated ICT system), performance, improvement of the working environment must to be developed and assessed.

The progressive reduction of waste (not only wasted materials, but also and particularly wasted design resources, wasted communications resources, wasted labour input on site,) becomes the guiding principle in seeking change within the construction process RTD can support the realisation of a ‘lean’, waste minimising, value-maximising perspective of the construction process through enhancing understanding of the process and the development of tools and techniques.

New business and site construction process, including increasing off-site manufacture and production, on-site automation, knowledge-based communicating teamwork, adapted materials… for an inherently safe, efficient and human-friendly production of buildings and infrastructure should be developed.

Industrialisation of the construction processes (industrialisation changes from an onsite construction process to a more controlled factory construction process) should be looked

4.3.2.2 Objectives

New Relations within the company, and other bodies associated with construction projects the role of technology

Development of solutions for incorporating construction projects in the social and economic fabric of a community during the difficult construction phase.

- Research for a New framework with high human relations factors for Hiring of labour and preparation for new technologies
- Development of innovative social communication systems for relations with third parties around the sites.
- New temporary supply network management systems, relations with companies and public bodies to reduce project implementation time.
- Research and Development of Safety of users and constructions adjacent to the site, advanced monitoring and management systems, on-line with automatic feedback.

Design: Final design to be built. Including the temporary works design.

Architecture: Creating visions and concepts. The human and social interface of the design. The interface with the surrounding environment.
**Engineering**: The process of converting the concept to a buildable design. Developing sets of calculations that show the scheme design works.

### 4.3.3. ICT and Automation

#### 4.3.3.1 State of the Art

**Communication technology**

Underground structures present a specific difficulty with regard to wireless systems and networks since the emission of radio waves in these types of spaces is complicated by the terrain itself and the artificial support and compartmentalisation structures which are normally thicker and denser than on the surface, and usually heavily reinforced.

Nowadays these problems are resolved using leaky feeders and/or distributed antennae, which reduce the advantages of wireless systems since they require the installation of greater infrastructure. The increasing use of these types of networks means systems capable of supporting a continually increasing bandwidth must be sought.

**Information Technology**

Development and research for engineering projects requires progress in process calculation and simulation techniques involved in their implementation. Currently, numerical calculation methods, such as the finite element method, are a widely used numerical tool in order to respond to the needs created in engineering projects.

The development of new numerical methods and finite element techniques is the future for the precise modelling of soil behaviour, the resistance behaviour of structures and the physical phenomena produced in underground works. It is the path for generating intelligent networks that enables analysis during execution. Based on the information captured by advanced sensors it is possible to obtain a behaviour model for preparing and taking real-time decisions.

It is vital to be able to reliably forecast all processes and phenomena produced in underground work for its correct design: study of the aspects related to the tunnelling process and building of the resistant structure; aspects related to the design of the characteristics of the tunnelling machinery tools; forecasting the behaviour of ground and structural elements, and assessment of their safety during service and in case of accidents (earthquakes, floods, explosions, fires, etc); environmental comfort aspects such as thermal, acoustic and physical comfort.

#### 4.3.3.2 Objectives

The objectives will be the implementation of ITC and automation in the underground construction in different important fields; they will be the basis of development of the other research priorities, and will play an important role in the transformation of the construction sector. Therefore the principle lines of performance are:

- Research and technology in design and management of intermediate stages, processes and evolving structures
- Development and Improvement in simulation of engineering processes
Approach and methods for “Security and safety analysis”

Research and technology in design and management of intermediate stages, processes and evolving structures

Development of innovations in the assessment, and study of structures at an intermediate stage of construction, temporary monitoring systems, and structure and construction behavioural prediction systems during intermediate phases:

- Research for Innovative movement forecasting and simulation systems
- Development for new systems for temporary coercion and systems for the monitoring thereof.
- New systems for the evaluation of materials of different types in terms of timeframes, origin of the products and climatology of the on site installation.
- Research for the evolution of construction processes in different frameworks and cultures, scope of enlargement of confidence for critical construction systems.

Development and Improvement in simulation of engineering processes

It groups those activities undertaken which are aimed at developing new project simulation, monitoring and management scenarios in real time. Oriented to obtain tools capable of:

- Incorporating innovations and technological advances into processes throughout the construction cycle, from design phase and its implementation. Including innovations related to technical responsibilities and appropriate technical guarantees.
- Model the tunnelling and excavation process
- To simulate the wear and abrasion of cutting tools of the machinery, and the degrading process of the construction equipment during the construction works
- Analyze an underground construction under service and exceptional loads and create a system for the localization of the dangerous loads

Approach and methods for “Security and safety analysis”

Development of an adapted integrated approach and of methods for “Security and safety analysis in complex underground systems” during all phases of life cycle

- Obtain new numerical methods to study the environmental impact and comfort of an underground building.
- Methods shall be developed both for the individual processes and for an integral approach to the entire system. Some module may exist (from existing EU projects etc) others must still be developed.
- Examples: safety optimised materials, integral safety approach in the construction process, safety concepts for large complexes of transport facilities, urban facilities and industry, etc.
- Development of an approach to handle and optimise safety of facilities in different life cycles

4.3.3.3 New knowledge generated
The knowledge that will be generated by the objectives is:

**Short-term**
- Advanced mathematical and numerical models to analyse the tunnelling process
- New numerical methods to simulate and study the wear of the mechanical elements of the construction equipment during the underground construction works.
- New Systems for the monitoring and evaluating of progressive structures over time
- Application of new technologies to increase the effectiveness of the wireless connections underground

**Medium-term**
- Development of basics for a system for the localization of dangerous loads during operation
- Development of new numerical methods to study the environmental impact and comfort of an underground building.
- Numerical tools to analyze an underground construction under service and exceptional loads
- Evolution of the technical tools for the communication in underground spaces.

**Long-term**
- Implementation of correct measures in the correct places in the case of incident.
- Complete monitoring of the infrastructure to forecast any possible incidence and have the maximum safety during all life cycle.
- Localization and continuous monitoring of fire/chemistry loads, their movements, etc. before the possible incident happens.

![TBM for Guadarrama tunnel](image_url)
4.3.4. High Added-value Construction Materials

4.3.4.1 State of the Art

In the various structural and non-structural components of underground infrastructures (tunnels, depots, deep storage, etc.) materials play an essential role, by their multifunctional nature, meeting resistance, durability, sealing and aesthetic requirements. On the other hand, of all of them, structural concrete (particularly including the concept concretes) is that used most widely in the field of underground infrastructures due to its adaptability to technical or engineering requirements (resistance and durability) as well as in terms of shape, aesthetic and others what this type of structure requires.

If it is a fact that current developments in Materials Science and Technology are capable of providing innovative and sustainable solutions, in line with the general current objectives of the 6FP. It is also true that the multiplicity of determining factors, which have a bearing on the different types of underground infrastructure, require a new focus to successfully lead future RTD: the design of solutions adapted to changing demands (using tailored-made materials). These solutions are integrated with new technology, procedures and materials, environmentally friendly and economical but at the same time capable of meeting the various needs arising during the lifetime of these structures and without overlooking safety and security measures during construction and the general satisfaction of the end user on completion.

4.3.4.2 Objectives

The large volumes of material moved during this kind of work require that both the responsible public works authorities and the technicians take into consideration, the concept of sustainability to apply it as a criterion to develop the high-performance, durable, subsoil-friendly, self-diagnostic materials. Main objectives

The development of new, adaptable, multifunctional tailored-made materials, capable of meeting the specific requirements of underground infrastructures defined in each case,
The development of intelligent or advanced new structural components or capable of responding to the different requirements which are presented in all phases of the project, and

The development of a non-destructive testing methodology, applicable at their actual scale, which enables the establishment of criteria suited to design as well as measures for monitoring and tracking work.

4.3.4.3 New knowledge generated

Tailored-made materials
Sustainable lining solutions adaptable to changing demands
NDT methodology

4.3.5. Attractive Workplaces

Social acceptance of tunnels.

4.3.5.1 State of the Art

Undoubtedly security together with the design of spaces and infrastructures are the most likely aspects to influence public acceptance of underground spaces due to the confined nature of such spaces and the resulting difficulty of excavation, lack of visibility and seriousness of the effects of certain emergency situations such as fires, explosions and floods, as well as other types of criminal acts or vandalism.

It is therefore necessary to make progress on matters related to the management of risks in all their aspects, from analysis through to establishing different strategies of action, which will be used to define emergency management protocols. It is also advisable to establish security-based criteria for inclusion in the design phase of the installations, with regard to the work planned.

In 2005 people hesitate for live underground there are some accepted features and some that still have not enough social acceptance:

- **Accepted:** waste storage, freight transport, shopping, parking, sporting, short distance travel.

- **Not accepted:** living, work, office spaces, long distances travel, not having a pilot/driver in charge

This tangible social understanding and assessment of the underground spaces give us some definitions of the today needs, to influence in public opinion for a good social perception the purposes are:

- Humans must feel safe in underground, in the same kind and manner as they feel on the surface.
- Vanish the terror of the possibility of a Terrorist attack
- Solve Contamination and negative pollution
- Take in account and find measures for risk originated from new technologies
- Improve the quality of live: health, contaminated areas, pollution, design aspects
4.3.5.2 Objectives

**Sustainable site and its surroundings**

It groups innovative performance aimed at all research activities whose aim is the conservation or improvement of the environment and safety, both on the site and on its surroundings. Thus an example would be:

- New technologies aimed at eliminating annoyance to users and people adjacent to the construction site, from reduction of dust, noise, access... etc.
- Innovative systems for improving signposting, temporary diversions, security fences for third parties...etc.
- New systems and technologies for exploitation and recycling of life consuming waste.

**New technologies applied to Installations auxiliary to the site**

This would group all projects aimed at research and development of systems to improve location, performance and temporary site facilities. We could list the following as examples:

- Development of new products, devices and services taking into consideration the sustainability, for the built environment for emergency and temporary construction technologies.
- Research for new types of temporary constructions for site facilities: impact and efficiency of designs.
- New research and development of assessment tools for intermediate states and evolving structures with temporary elements included or involved during the construction phase. cradling, formwork, scaffolding, access systems...
Assess and specify the human requirements of future use of underground spaces

‘Use’ comprises a broad range of human activities: from transportation to recreation, as transfer or work space, for short-term and long-term stay underground. Human requirements cover social, psychological, and physical aspects of human functioning, concerning areas like:

- Safety, Security, Health, and Comfort
- Information Mental appreciation
- Human relationships

Development of new technologies for healthy and safe Workplaces

Development of a new Workplace healthy and safe: dealing with site workplace health and Safety performance. Thus we would have:

- New friendly processes for smart and automatically evaluating hazards and uncertainties in the construction processes at project and site level.
- Development of new systems for preventing workplace hazards, independently of the worker's will.
- Research for new technologies in Innovative systems for the prevention, detection and fighting fire on sites as well as evacuation of personnel in case of emergencies.
- New clever fixed and mobile safety systems to avoid injury to third parties, as well as to workers, caused by machinery and equipment used in construction.

4.3.5.3 New knowledge generated

Approach for “User friendliness”

Development of an adapted integrated approach and of structural measures for “User friendliness in complex underground systems” during the operation.

- Humans feel underground as safe and secure as above ground. Light, design of infrastructure (large, open areas, much place etc.).
Simple and inviting accesses to escape possibilities etc. One should save oneself underground in such a way as above ground.

Humans want to feel safe and that there is always a way upward (emergency exits, emergency route/stairs, and rescue areas). One goes stress-free, without panic, relaxed into another area etc. or at the surface again.

Modelling of Safety, Security, Health, and Comfort factors from Underground spaces

spaces that are adapted to the needs of people

- Physical conditions
- Psychological conditions
- Social conditions
- Safety /Evacuation
- Health /Clean air Noise levels
- Comfort /Temperature Sound Light

Modelling of Psychological factors related to use of underground spaces

develop space-educated people that make optimally use of societal accepted underground spaces

Modelling of Social factors as affected by using Underground spaces

identify support processes and organisational structures for safe, secure, and comfortable use of underground spaces

- Information management
- Orientation; Mental maps
- Behaviours of Crowds and Masses
- Social Safety
5. Making the Vision a Reality

5.1. Implementing the Research

The implementation of this Research Strategy will involve a combination of collaborative research instruments and of Joint Technology Initiatives. The European Construction Technology Platform has the capacity to generate Joint Technology Initiatives. An initiative is today already under preparation.

The construction of very large infrastructure projects could provide an excellent opportunity to develop Joint Technology Initiatives in the Construction Sector. Past examples such as the construction of the Channel Tunnel demonstrate that such large projects combine many characters of the JTIs:

- Based on private funding
- Association of a very large number of stakeholders
- Size and ambition of the project, responding to a major social need
- Innovative character of the technology employed
- Large impact on the competitiveness and public image of the Construction Sector.

5.2. Collaborative and new Project management

Those Joint Technology Initiatives have the aim of improving construction project management considering the possibilities of:

- Research in new collaborative and advanced construction process management systems
- Development of new and smart integrated systems for the transmission of information to the bodies and departments concerned
- Research in new technologies to meet the needs of staff suitably qualified to deal with projects.

At the same time there are different aspects in the project management related in linking the research with the creation of value. Some important clauses will be treated in a complementary way:

- Dissemination and profitability.
- Innovation in Management issues and transmission of technical knowledge.
- Research in new Contracting: subcontractors and suppliers, the whole supply chain.

5.3. Dissemination and profitability

Objectives

? Research current methodologies and tools used in distance training, active management of knowledge and virtual learning for their development in domestic and international research networks and projects.

? Propose an Active Knowledge Management System (which enables the structured transmission of knowledge and experiences) for the construction
sector in Spain, within the area established and recognised by the sector (must be sufficiently versatile for adaptation to the different characteristics of companies in the sector).

? Develop collaborative work skills between project researchers, contributing towards the creation of a new participative policy in research and transfer relationship with companies. Create specific joint university-company actions in the fields of active knowledge management training and learning.

? Establish training plans which include the knowledge necessary for the development, based on all the knowledge generated in each of the subjects of this strategic area.

? Establish and identify the characteristics of the virtual learning systems, analysing their features and improvement possibilities with the inclusion of new “haptic” elements (devices that generate tactile sensations).

? Establish new work framework, developing new training and virtual learning tools, and establishing systems for assessing the degree of satisfaction and use of users.

Although it may seem obvious, it should not be forgotten that the objective of any technological or business innovation idea is the value creation. This is achieved by exploiting changes made to the full, applying the results of the R+D+I either in the company itself or outside in the market.

Consequently, the definition of the different needs, the aim of each of the research priorities, will contribute to the general aspects of:

? Dissemination which will aim to:

- Establish adequate communication channels between the project management team and private and institutional agents able to present the results obtained, as well as the scientific-technological community in the main.
- Attract both specialist and general media interest in “the multi-dimensional city” project, its progress and achievements.
- Develop actions that serve as advertising vehicles in the national and international contexts determined.

? Dissemination or coordination of tasks designed to spread knowledge obtained between professional and business agents of the value chain of underground construction work, with the following aims:

- Facilitate the inclusion in other companies and professionals of the value chain of new ideas, processes or techniques resulting from the project worth making public, i.e. not considered necessary protecting specifically using IPR instruments.
- Promote technological grouping with collaborators.

? Use or coordination of tasks for legal protection and the economic implementation of the know-how generated in the project with two different modus operandi:
- Actions designed to internalise the results (ideas, procedures, techniques etc) within the companies with regard to the inclusion of its own production processes in the general context of the application that represents the scope of the focus area.
- Actions for converting the part of interest from the know-how generated throughout the project into intellectual property rights and/or industrial property rights so that these rights can be exploited economically by their links in domestic and international technology markets.
- This concept also includes marketing actions designed to estimate the commercial potential of the IPR generated in the project, client identification and target markets, as well as define technological sales strategies suited to the aims established.

Innovation in Management issues and transmission of technical knowledge

It would group innovative activities where the objective is to deepen information management and transmission and company knowledge, in order to bring the research and innovation project results to projects, including the necessary technical support for carrying this out.

Examples of research and development projects which would come under this section are:

- New dissemination tools for Intranet/Internet-based content management systems
- Development of new Workplace technologies for communicating with people in different languages and of different cultural backgrounds.
- Research and development of new evaluation systems of the implementation of innovations and the R&D results transferred to jobsite activities and to satisfy Client’s requirements.

Research in new Contracting: subcontractors and suppliers, the whole supply chain

It includes innovative activities aimed at developing new and equitable with technology improvement capabilities, with the most adequate contractual relationships between the different bodies involved in construction processes: project designers, subcontractors, suppliers, clients.

- Research for a collaborative network for a new framework for Strategic alliances for innovative development
- Development of new technologies and outputs for Joint exploitation of results
- New Business opportunities based in technology and research for exclusive construction systems
- Research to build and develop a network of Engineering concurrent with construction processes
- Research and Development of Evaluation systems based on the overall life-cycle of the construction applied to contracts signed and in execution from the Contractor side.
5.4. Training and Education

The Sector is already facing a shortage of skilled young people, partly due to demographics and partly due to the reduced attractiveness of industrial activities, when compared to other activities such as finance and services.

First action is to engage the Sector in massive research efforts to change the Sector profile towards a knowledge-based, demand-driven sector, and to base these efforts on cooperation with academic partners.

Research in the Sector combines a wide scope of technologies with environmental, economic and social issues; it requires a careful cross-disciplinary critical analysis of the construction process from both builder’s and user’s perspectives. It will also require defining with academic partners the best suitable sets of training programmes with a suitable dosage of specialisation and multi-disciplinarily.

Training the personnel is another priority, a necessity of any knowledge-based process. The objective is to bring high level knowledge to the closest point of its application—ideally, on the construction site itself. New training methods, new training tools must be developed with cooperation of academic partners to reach this goal. The main purposed objectives can be summarized as:

**Objectives**

Although innovation in training and learning is difficult to achieve, new guidelines in the training area are going to be implemented as a project novelty. Innovative lines that can be drawn from here are as follows:

**Active knowledge management**

Creation of a management system that enables the structured transmission of knowledge and experiences for the construction sector in Spain adapting to the different characteristics of the companies within the sector, with it being dynamic and structured.

**Training**

Creation of a new platform for adaptation or use of an existing platform for distance training with the best proposals, mainly aimed at improving teacher-student interactivity, quality control and the use of new multimedia and connectivity tools.
Virtual learning

Construction of a generic simulator prototype which includes, as far as possible, the characteristics forecast for future simulators is planned: configurable and with a very direct interaction with the projection system.

International cooperation is another suggested path: knowledge exchange programmes, mobility schemes, international training addressing both developed and developing countries can be used to transfer European experiences, raise awareness on sustainability in other countries, and ultimately to provide new opportunities for European stakeholders on overseas markets.