STIFTELSEN BERGTEKNISK FORSKNING
ROCK ENGINEERING RESEARCH FOUNDATION

INNOVATION PROCESSES AND DISSEMINATION OF RESEARCH-BASED KNOWLEDGE IN SWEDISH ROCK ENGINEERING

Experiences in the TRUST GeoInfra project

Anna Kadefors
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Innovationsprocesser och spridning av forskningsbaserad kunskap inom svenskt bergbyggande

Erfarenheter från projektet TRUST GeoInfra

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PREFACE

Research and development within rock construction and design is important to allow more complex projects in the future in a challenging environment. Despite this, there is relatively little investments in R&D compared to other industries. And that is why this study is important and provides some insight into how research is conducted and comes into practical application.

This report summarises and discusses results of interviews and workshops conducted with representatives of clients, contractors, consultants, researchers and funding agencies in the research program Transparent Underground Structures (TRUST). The TRUST project or network consisted of eight separate research projects funded by primarily the FORMAS research program GeoInfra, the Swedish Transport Administration, the Rock Engineering Research Foundation (BeFo) and the Swedish Construction Industry Development Fund (SBUF). The GeoInfra program was initiated to meet an experienced need for knowledge, methods and technology to support future major investments in underground construction in urban environments. The report describes the innovation processes and the dissemination of knowledge in Swedish rock engineering research in general and within the TRUST project in particular.

The studien primarily conducted by Anna Kadefors (KTH, Royal Institute of Technology) and Thomas Olofsson (Luleå university of technology) assisted by the project leader for TRUST, Maria Ask (Luleå university of technology). A referens group supported the study and consisted of Peter Lundman (previous Swedish Transport Administration), Mats Svensson (Tyréns), Håkan Rosqvist (previous Tyréns), Eva Widing (SKB) Lars Olof Dahlström (previous Chalmers institute of technology/NCC) and Per Tengborg (BeFo).

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Per Tengborg

FÖRORD

Forskning och utveckling inom bergbyggnadsområdet är nödvändigt för att i framtiden kunna bygga alltmer komplexa anläggningar i utmanande miljöer. Trots det satsas det förhållandevis lite på FoU jämfört med andra branscher. Och just därför är denna studie viktig och ger en viss insikt i hur forskningen bedrivs och kommer till praktisk nytta.

Rapporten sammanfattar och diskuterar resultat av intervjuer och workshops utförda med representanter för byggherrar, entreprenörer, konsulter, forskare och finansieringsorgan med anknytning till forskningsprogrammet Transparent Underground Structures (TRUST). TRUST-programmet kan beskrivas som ett paraplyprojekt med åtta separata forskningsprojekt som huvudsakligen finansierades av FORMAS forskningsprogram GeoInfra, Trafikverket, Stiftelsen Bergteknisk Forskning (BeFo) och Svenska Byggbranschens Utvecklingsfond (SBUF). GeoInfra-programmet initierades för att möta ett upplevt samhällsbehov för kunskap, metoder och teknik för att stödja kommande stora investeringar i undermarkbyggande i urbana miljöer. Rapporten beskriver innovationsprocesser och kunskapsspridningen inom svensk bergteknisk forskning i allmänhet och inom TRUST-projektet i synnerhet.

Studien har främst utförts av Anna Kadefors (KTH) och Thomas Olofsson (Luleå tekniska universitet) med bistånd av projektledare för TRUST, Maria Ask (Luleå tekniska universitet). En referensgrupp har bistått projektet och bestod av Peter Lundman (f d Trafikverket), Mats Svensson (Tyréns), Håkan Rosqvist (f d Tyréns), Eva Widing (SKB) Lars Olof Dahlström (f d Chalmers/NCC) och Per Tengborg (BeFo).

Stockholm, 2019

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SUMMARY

Innovation in the project-based construction industry is generally perceived to be complex and poorly understood on a system level. This report describes and discusses the innovation system in Swedish underground construction based on a study of knowledge dissemination and implementation in relation to the large collaborative R&D program TRUST, Transparent Underground Structures.The study is primarily based on interviews performed with representatives of clients, contractors, consultants, researchers and funding bodies within the TRUST program. There are two main focus areas: the innovation system level and the TRUST project. The innovation system level describes drivers, organization and processes for engaging in R&D and implementing results within the Swedish Transport Administration (STA), contractor companies and consultancy firms, but also interviewee opinions about the innovation culture in Swedish rock engineering and construction more generally. The section covering the TRUST project describes the background, performance and experiences from the TRUST collaboration as well as innovation processes within some of the sub-projects.

Underground construction is a part of the construction sector where comparatively much research is carried out and university-industry collaboration is lively. Still, our results confirm many of the observations made by previous researchers on innovation in construction in general: the small resources within companies devoted to research and innovation, the importance of champions at the project level and the difficulties to disseminate knowledge and implement company level initiatives. The contractor interviews illustrate how sensitive their innovation processes are to chance factors such as timing of new relevant business projects and the experiences and knowledge of the individuals that happen to be assigned to a specific project. In this respect, the client is more in control. However, the interviewed client representatives from STA express the same kind of difficulties in driving innovation more strategically on the organizational level and convince their project managers to open up for R&D tests and new knowledge in their business projects.

Previous research has also shown that there are many drivers for firms to engage in R&D collaborations with public funding. R&D collaboration provides access to knowledge networks by enabling participation in reference groups and communities. Important such networks in Swedish underground construction were BeFo and SBUF. Another driver for R&D collaboration was to support M Sc and PhD education for future recruitment. Thus, the individuals themselves were often the most important research output. Implementation of results was not a primary motivation although a more strategic approach was emerging among both public organizations and private companies, who put more emphasis than they used to on application in practice of research results. One consultancy company was especially active in developing their R&D strategy to support a business model based on premium services. In general, however, knowledge development for underground construction was still mainly driven by individual specialists based on their contacts in business projects. Organizations had developed centrally defined R&D strategies, but these did not deal explicitly with technical disciplines but tended to focus on general goals such as sustainability, or on participation in high profile research collaborations.

Most specialists within academia as well as industry were involved in several networks and perceived these to provide useful interaction platforms. Research funding was governed by BeFo and SBUF, and these peer networks thus strongly influenced research strategy on a national level. The number of PhDs in industry had increased over the last years, and important informal networks developed over time between these individuals and their former university departments. Such relationships formed the basis for gaining research funding, which is often dependent on industry co-funding.

When establishing TRUST, the assumption was that a large coordinated R&D project would be better for communicating with industry and implementing results than several smaller projects. However, it turned out to be more or less the other way around. The existing system could handle innovation in construction projects, but not innovation on the organizational level. This became apparent when trying

to find a joint test site. In smaller research projects, access to business projects is provided by individuals on the client or supplier side, often with an R&D background, who use their personal contacts to provide access to researcher to perform measurements in ongoing construction projects. This often requires that site work is going well and that measurements are found not to cause too much disturbance. Large programs for site measurements involving numerous actors, such as TRUST, call for planning and upfront commitment. The failure to arrange fieldwork in TRUST illustrate the difficulties to take the step from a bottom up, ad-hoc, individual based regime to an organizational strategy with national level anchoring and implications. Thus, the TRUST program appeared to be an ideal partner for the Swedish Transport Administration, but in practice the size of the project turned out to be a major disadvantage.

In general, the internal innovation capabilities of companies and client authorities need to be developed in order for organizations to benefit from the collaborative research programs and act upon the knowledge developed. One aspect is that measures should be taken to more explicitly involve business project managers in both R&D and implementation. Innovation capability development is needed especially on the client side, since long term strategies in supplier organizations will not develop if the strategies of the dominant clients is not clear. However, assuming that the geo area in general is largely an open innovation environment, it also seems useful to explore if different actors could perform complementary activities in an industry innovation system. For example, specialist networks both within organizations and on the industry level may be more formally mobilized in external monitoring, strategy development and evaluation. In the future, top management, technically oriented specialists and researchers need to develop a joint understanding of how the innovation system works, including the regulatory and contractual environment.

There is also a need to invest also in research that is relatively far from application. Thus, evaluation processes and output measurement systems should be adapted to how close to implementation the research project is and also assess the need to build capabilities on the receiver side.

SAMMANFATTNING

Innovationsklimatet i den projektbaserade byggindustrin är komplext och dåligt undersökt på systemnivå. Denna rapport beskriver innovationssystemet inom svenskt undermarksbyggande med utgångspunkt i en studie av kunskapsspridning och nyttiggörande i det stora forskningsprogrammet TRUST, Transparent Underground Structures. Resultatet baseras huvudsakligen på intervjuer med representanter för beställare, entreprenörer, konsulter, forskare och finansieringsorgan. Två nivåer har studerats: dels det övergripande innovationssystemet inom undermarksbyggande och dels TRUST-programmet. Innovationssystemnivån beskriver drivkrafter, strategier, organisation och processer för att engagera sig i FoU och implementera FoU-baserad kunskap i affärsprojekt inom Trafikverket, entreprenadföretag och konsultföretag, men även hur olika parter ser på innovationskulturen inom svenskt undermarksbyggande mer generellt. För TRUST-programmet beskrivs bakgrunden och de erfarenheter som gjordes, samt spridning och implementering av forskningsbaserade resultat inom några av delprojekten.

Undermarksbyggande är en del av byggsektorn där jämförelsevis mycket forskning genomförs och där samarbetet mellan universitet och industri är relativt väl utvecklat. Våra resultat bekräftar dock vad tidigare forskning om innovation i byggandet mer allmänt har visat: att företagen lägger förhållandevis små resurser på forskning och innovation, att eldsjälar som kan driva utveckling på projektnivå har stor betydelse och att drivkrafterna för att implementera innovationer och svårigheterna att sprida kunskap från forskningsprojekt till företagsnivån är svaga. Intervjuerna med entreprenörerna illustrerar hur beroende deras innovationsprocesser är av rätt timing med relevanta affärsprojekt och av att det finns relevant erfarenhet och kunskap hos de individer som medverkar i ett enskilt byggprojekt. Leverantörerna ser beställarkraven som avgörande för sina FoU-investeringar. Men en entreprenör vet inte i förväg vilka affärsprojekt som kommer ut på marknaden och vilka anbudstävlingar de kommer att vinna. I detta avseende har beställaren större möjligheter att planera långsiktigt, men intervjuade representanterna för Trafikverket uttrycker liknande svårigheter som entreprenörerna när det gäller att driva innovation på en mer strategisk nivå.

Tidigare forskning har också visat att det finns flera drivkrafter för företag att delta i FoU-samarbeten med offentlig finansiering. En är att FoU-samarbete ger tillgång till kunskap och nätverk genom deltagande i t ex referensgrupper och branschråd. Viktiga sådana inom svensk bergforskning är BeFo och SBUF. Ett annat mål med FoU-samarbete är att stödja utbildningen av civilingenjörer och doktorander för framtida rekrytering till branschen. Att erbjuda deltagande i forskning som del i tjänsten var också ett sätt för de medverkande organisationerna att både behålla och rekrytera personal. Således är individerna som deltar i forskningsprojekten ofta det viktigaste resultatet, inte forskningsresultaten i sig. Implementering av resultat är mera sällan den primära motivationen för företag att satsa på forskning, även om studien visar att både offentliga organisationer och privata företag börjar lägga allt större vikt vid den praktiska tillämpningen. I TRUST-projektet var ett konsultföretag särskilt aktivt med att utveckla FoU-strategier som grund för en delvis ny affärsmodell där man vill konkurrera med unik kompetens istället för med pris på en globaliserad marknad. Men generellt drivs kunskapsutvecklingen inom undermarksbyggande fortfarande i stor utsträckning av individer med specialistkompetens. De medverkande organisationerna hade centralt definierade FoU-strategier, men de behandlade inte målsättningar inom tekniska discipliner utan fokuserade på övergripande områden som hållbarhet, eller på deltagande i högprofilerade forskningssamarbeten av flaggskeppskaraktär.

De flesta specialister som deltog i TRUST-projekten, både inom akademi och industri, medverkade i flera olika professionella nätverk och menade att dessa var viktiga och användbara plattformar för samarbete och kunskapsutbyte. Antalet forskarutbildade inom området har ökat under senare år och viktiga informella nätverk utvecklas över tid mellan disputerade specialister som nu arbetar i näringslivet och deras tidigare forskningsmiljöer på universiteten. Sådana nätverk utgör ofta basen för att ansöka om nya forskningsprojekt, vilka i allmänhet förutsätter medfinansiering från industrin.

När TRUST startades antog initiativtagarna att ett stort samordnat forskningsprojekt skulle var en fördel jämfört med flera mindre projekt när det gällde att kommunicera och implementera resultaten. Detta visade sig emellertid inte stämma, utan istället var det snarast tvärtom. Detta blev särskilt tydligt när man skulle hitta en gemensam plats för fältförsök, vilket Trafikverket hade utlovat inför planeringen av TRUST. I enstaka, mindre FoU-projekt är det enskilda specialister, ofta med forskarutbildning, på beställar- eller leverantörssidan som använder sina kontakter för att bereda access för forskarna att genomföra försök i pågående byggprojekt. Detta förutsätter i allmänhet att byggarbetena går bra och att mätningarna inte stör produktionen. Större program för fältförsök som involverar många olika parter behöver dock planeras och beslutas långt i förväg. Att man inte lyckade med detta i TRUST visade på svårigheterna att ta steget från individbaserade FoU-strategier till en centralt förankrad långsiktig strategi med effekter på den nationella nivån. I teorin framstod TRUST som en ideal samarbetspartner för Trafikverket, men i praktiken visade sig projektets storlek vara en nackdel.

En viktig slutsats av studien är att system och resurser inom organisationerna behöver stärkas för att kunna dra bättre nytta av den kunskap som tas fram i forskningssamarbeten. Inte minst borde projektledningen i affärsprojekten bli mer involverade i FoU-projekt. Särskilt är det beställarnas innovationsförmåga som behöver utvecklas, eftersom detta är en förutsättning för långsiktig utveckling på leverantörssidan. Eftersom undermarksbyggandet i stor utsträckning är ett öppet innovationssystem borde det även finnas stora fördelar i att etablera strukturer för olika aktörer kan samverka i att fylla kompletterande funktioner i ett innovationssystem på branschnivå. Exempelvis kan de professionella nätverken mobiliseras mer systematiskt i omvärldsbevakning, strategiutveckling och utvärdering. I framtiden behöver forskare, ledningsfunktioner och tekniska specialister inom olika organisationer skapa en gemensam förståelse av hur innovationssystemet fungerar, inklusive den legala och kontraktsmässiga kontexten.

Det är också viktigt att branschen investerar i forskning som är längre från implementering. Detta innebär att uppföljningssystem och mätetal behöver anpassas till hur tillämpningsnära forskningsprojektet är, och även ge en bild av behovet av att utveckla kompetens och resurser på mottagarsidan.

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1 INTRODUCTION

1.1 Background

Following urbanisation, the volume of underground construction for the provision of transport and other urban facilities has grown in Sweden, a trend that is planned to continue the coming years. The urban context implies increased geological complexity and higher environmental requirements regarding for example surface settlements, groundwater pollution and noise and vibrations due to underground construction. Thus, various actors in the underground construction area – including academia as well as funding bodies, industry and public clients, saw a need for research to promote development of knowledge and new engineering methods, also considering advances in information and communication technology. There was also a perceived need to know more about user aspects affecting design of underground space, for example combining architectural and technical competencies. As a result of several years activities to raise awareness, the Swedish Research Council Formas and the Swedish Transport Administration in 2012 issued a joint call for trans-disciplinary research in this area: the GeoInfra call.

An alliance involving six universities, Transparent Underground Structure (TRUST) managed to secure funding for eight projects, altogether comprising over 7MEUR. The aim of the alliance was to establish a collaborative arena to develop and facilitate implementation of methods and technology for the entire process of planning, engineering design and construction of urban underground structures. In accordance with the funding requirements, all TRUST sub-projects were co-funded by industry, either in cash or in kind.

This report summarises and discusses results of interviews performed with representatives of clients, contractors, consultants, researchers and funding bodies within the TRUST project. There are two main focus areas: the innovation system and the TRUST project. Researchers on innovation systems (Malerba, 2005; Bergek et al., 2008) have identified institutions, actors and networks as key structural components of an innovation system in a specific sector. Other researchers claim that the internal structures and competences of organizations determine their capacity to absorb new knowledge and implement research results. (Zahra and George, 2002).

The institutional aspect is summarised in section 1.2 below, where basic principles governing innovation in the construction sector are described. Chapter 2-4 covers the actor level and outlines the drivers, organization and processes for engaging in R&D and implementing results of the Swedish Transport Administration, contractor companies and consultancy firms. In Chapter 5, the views of all interviewees on innovation in rock engineering on the industry level are described, including the role of networks. Chapter 6 and 7 outline the innovation processes in the TRUST projects. Finally, the results are discussed in Chapter 8 and conclusions drawn in Chapter 9.

The interview themes differ somewhat between interviewee categories but together include:

- Drivers for investing and participating in research
- Strategy, process and organization for initiating and selecting R&D and development projects
- Evaluation and implementation of research results, knowledge dissemination
- Culture and openness to new knowledge
- Drivers for and obstacles to R&D and implementation
- Collaboration between industry and academia as well as between scientists

1.2 Institutional level: innovation in construction

Research on innovation in construction has established a good understanding of the specific conditions that this context presents when it comes to learning and innovation. Below we summarise five key aspects based on research in the area.

1. Construction innovation is difficult to measure and compare

Construction is undoubtedly a mature industry with a low rate of innovation. Judged by conventional statistics, R&D expenditure of contractor companies is nearly negligible in relation to their turnover (Reichstein, 2005; Slaughter et al., 2014). However, conventional statistics and comparisons are partly misleading for this industry (Winch, 2003). One reason is that it is not evident how to differentiate between R&D project and business projects, since less radical innovation is part of the design phase of all construction projects (Slaughter, 2008). Most of this development work is outsourced to independent architectural and engineering firms and do not show as R&D in statistics focused on contractor firms. Thus, actual R&D investment and engagement are often higher than these figures indicate.

A related line of argument is that not only architectural and engineering firms but also construction companies essentially sell services and not products, and in terms of both productivity development and innovation therefore should be compared to business service providers rather than to manufacturing (Bröchner, 2013.

2. Construction is an open innovation environment

Construction projects are performed in temporary project organizations that often involve a large number of firms. Individuals and companies work together to develop unique solutions, and over time they accumulate relevant knowledge that they bring into new projects. That suppliers have to continuously adapt to different clients with varying requirements, and to projects with varying problems, is seen as one of the prime obstacles for contractors and consultants to invest in innovation and learning (Eriksson, 2013). This transitory organizational context further implies that appropriability conditions are not favourable, meaning that it is hard for a company to benefit from investments in innovation (Malerba, 2005). Patents are less common outside the material and equipment producers (Bröchner, 2011). Instead, problems occurring in a project are key drivers for innovation (Winch, 1998; Loosemore, 2015).

3. Clients are key to innovation

Market demand is a key determinant in theories of innovation systems, and clients have a pivotal role in shaping the incentives for innovation in the construction industry (Nam and Tatum, 1997; Blayse and Manley, 2004; Brandon and Lu, 2008; Loosemore, 2015). Clients can drive innovation by higher requirements, but may also effectively obstruct innovation. For infrastructure construction, one or a few public transportation authorities are generally dominant in shaping conditions for innovation in a region or country.

Regarding the innovation capabilities of clients, studies have shown that many of them are conservative (Ivory, 2005; Hartmann et al., 2006; 2008). Sometimes this is for good reason: innovations entail risks, and a variety of technical solutions in an owner's property stock - initiated in various projects over time - may raise costs for operation and maintenance (Holmén et al., 2017). Experienced clients with strong in-house organizations have been found to innovate more than non-professional clients (Slaughter and Cate, 2008), but some public sector clients have been described as large bureaucratic structures that resist change (Hartmann et al., 2006). Altogether, there does not seem to be a straightforward relationship between the general size and competences of clients and their innovation capacity.

4. Innovation is project-based and decentralized

Following from the temporary construction projects, organizations in the construction industry – design consultants and contractors but also the building departments of clients – are project-based. Development work in the construction industry primarily takes place in business projects, but it is difficult to spread successful innovations between projects (Heiskanen, 2015). Many studies have shown that structures and routines for driving innovation on are seldom much elaborated in these organizations (Gann and Salter, 2000; Toole et al., 2013). Decentralisation is high and it is difficult for top management to influence project level operations. In effect, the freedom to initiate innovation at the project level is hard to reconcile with strong structures for systematic learning on the organizational level (Dubois and Gadde, 2002). This dilemma is mirrored on the industry level, where a pervasive standardisation of roles, routines, components and designs facilitates coordination and favours efficiency in the short term but also hampers innovation (Kadefors, 1995).

5. Innovation relies on individuals

The decentralised innovation practices imply that individuals play important roles in driving innovation in construction. Innovation often results from initiatives by highly motivated and technically skilled champions who push their ideas through the system (Nam and Tatum, 1997; Hartmann et al., 2008, Loosemore, 2015). Information dissemination and retrieval is strongly linked to individuals and their networks, using face-to-face communication (Styhre et al., 2006; Gluch et al., 2013). Knowledge is spread as actors bring the knowledge and experiences gained in one project to the next project carried out in a new constellation.

These five themes are highly interrelated. They jointly reflect and explain what is specific about construction and the factors constraining and enabling innovation in this field. It is obvious that technology shapes institutional structures to a great extent. The reason why it is meaningful to discuss innovation in the construction industry as a special case is that the products – buildings and infrastructure – are large, expensive structures that occupy a specific piece of land (often attractive urban space) for a very long time.

1.3 Research on university-industry collaboration

Hampson et al. (2014) provide a global overview of R&D investment in the construction sector, and it is clear that collaborative research, often publicly funded, constitute a major part of such investments. Evaluating the performance of such networks, Dewulf and Noorderhaven (2011) compared collaborative research programmes in four countries and found that difficulties in establishing true collaboration between industry and academia were common. These problems were generally based in actual misalignments in incentive structures (short term/long term orientation, practical output/academic output). Evaluations of Swedish collaborative programs have shown that implementation rates are low in programs that involve universities (Kadefors and Bröchner, 2014). In a study of R&D collaborations within sustainable urban development Polk (2014) found that a significant obstacle both to developing new knowledge and to implementation was that the public servants participating in the projects generally could put in very little time, especially those with key positions. Relevance played a comparatively smaller role. A study of a learning arena for energy-efficient renovation involving housing companies, researchers and government actors (Gluch et al., 2013) showed that the research partners found the collaboration very useful while it was hard for organizations that lacked clear goals, resources and research experience to benefit from their participation in the network. In kine with the findings of Schartinger et al. (2002), a lack of in-house knowledge resources such as qualified scientists and engineers may inhibit both internal and external knowledge accumulation. This further implies that there are size effects, so that larger firms with more R&D are better equipped to evaluate and exploit external sources of knowledge.

In a study of collaborative R&D partnerships, Thune and Gulbrandsen (2014) found that these were formed generally based on existing social relationships and mobilized by universities and other public research organizations, often to develop a proposal in response to a call from a funding body. However, in many cases industry partners were not very active during research. They didn't have specified goals when they joined the partnership but rather there was a "nice to have" type of motivation, such as gaining access to frontier knowledge and networks. Perkmann and Walsh (2007) as well state that the value to firms of collaborative research, especially if its publicly subsidised, is generally more related to capacity building, learning, social capital and signalling effects than to any tangible output.

Further, strong and close relationships do not seem to be the most innovative. For R&D partnerships, Fitjar et al. (2016) found that medium proximity levels were optimal for cognitive (similar knowledge base), organizational (similar organizational structures), and social and institutional proximity, and that firms collaborating with partners at a longer geographical distance were actually more likely to innovate. A study by Steinmo and Rasmussen (2016) showed that this may differ between types of firms: for science-based firms cognitive and to some extent organizational proximity were most important, while engineering-based firms were more likely to rely on social and geographical proximity.

2 THE SWEDISH TRANSPORT ADMINISTRATION

2.1 Strategy, process and organization for R&D and development projects

The Swedish Transport Administration (STA) has a government directive to fund and engage in R&D. STA was established in 2010, as a result of a merger between the former Swedish Rail and Road authorities. The annual research budget is around 500 million SEK, or 50 MEUR. The research organization was changed in 2017, but during the period studied research projects were divided into ten portfolios, seven of which corresponded to Strategic Challenges defined at the STA board level. Each portfolio was governed by a Portfolio Board, headed by a Portfolio Sponsor. Sponsors and board members are representatives of various organizational units considered to be potential users of the research results. There was a direction document for each portfolio. The system for funding application was perceived by interviewees as more formalised and involving more bureaucracy than it used to be before the merger.

About 300 MSEK are invested in long term research centers and programs on national or European levels, while 200 MSEK are free. Most research in underground structures was related to two portfolios: primarily number 5 “More value for money” but to some extent also number 4 “Robust and reliable infrastructure”. The Swedish Rock Engineering Research Council (BeFo) had a long-term funding commitment within Portfolio 5, and STA is the largest financial contributor to BeFo. In addition to the STA research budget, there is a budget for business development. All such development used to be funded by the Business areas, but approved by the Portfolio boards.

2.2 Drivers to engage in R&D collaboration

According to interviewees, the most important driver for STA to engage in research is that there is a government directive, and government also sets the direction of research to some extent. STA is required by government to fund some research environments, such as the VTI (Transport Research Institute). The government directives further prescribe that STA should primarily fund applied research that is important to the organization itself. According to interviewees this implies that the STA needs to be more actively involved in research than before and also collaborate more closely with the industry.

According to interviewees, the strongest driver both to initiate research and implement results occurs if there is an acute problem in a construction project that has to be solved. The opportunity to save time and money was mentioned as a major driver. However, such savings have to occur in the individual construction project. One view, however, is that potential cost savings do not act as a strong driver for R&D investment in a public sector environment where funding is distributed on the basis of politically set plans. Instead, other political goals may be more important, and especially environmental goals and work safety have been in focus the last years. Legitimacy issues can also act as a driver: if media criticises the STA, as has been the case for railway maintenance, it can be important to show that the STA is engaged in research in that area. There may also be a technology push, and BIM (Building Information Modelling) is seen as the main example of this.

Research is further considered to be important as a basis for recruitment of personnel for STA as well as the industry in general, both PhD students and civil engineers. This requires university environments that perform research. Participation in research may also function as competence development for STA personnel, where research collaborations become arenas for joint learning and knowledge exchange. Personal interest and commitment of individuals is another key driver to initiate research activities, and possibilities to participate in research is important in order for STA to attract and keep competent employees.

2.3 Selection of R&D and development projects

As already mentioned, the trend towards more applied research implies that while research projects were previously initiated and designed by university researchers, the STA now has to define its own needs to a greater extent. This is perceived to be an important change, but interviewees say that there is no clear strategy or governance structure for defining research priorities within a specific area such as rock engineering. The research portfolio direction documents are organized around high level, general strategies and not according to the needs of functional areas. As one interviewee said:

> "We can do everything that is described in terms of sustainability, work safety and the Pure Client Role", but nothing else".

As an example of the lack of strategies for functional areas, he mentioned a project to develop underground planning which the STA specialists had been suggested for 15 years. This project had recently been approved for funding by the STA, but then as an environmental project under the Environmental Objectives Council (Miljömålsberedningen) and driven by the Swedish Environmental Protection Agency.

One view expressed in the interviews was that the STA should focus more on strategic approaches and road maps to guide the development of rock engineering knowledge, this since Sweden is planning considerable investments in underground construction the coming years. It was considered especially important to develop knowledge and methods to balance between investment costs and maintenance costs for tunnels in different contexts. For example, investing in a more expensive "low-maintenance" urban tunnel alternative might be wise considering the total cost of ownership. Such decisions have to be made early in a project since it is difficult to introduce more costly solutions that increase the project budget in later stages.

Within the rock engineering area, the research funding from the STA is channelled to BeFo. A board of client, contractor and consultant members sets the research priorities of this organization. Such long-term funding commitments imply that STA research strategies are mediated by industry level collaborative decision-making. Moreover, interviewees emphasized that STA R&D activities in underground construction are highly dependent on individuals, and that strategies are personal and not related to the organizational level. One important implication is that research activities and implementation frequently stop if, for example, there is a change in project organization or if an important person quits.

Thus, many suggestions for R&D projects come from employees, and especially the technical specialists have a key role. When the STA was initiated, around 25 competency networks were formally established for STA specialists within different units to communicate and collaborate. There is one Rock and Tunnel network and one for geotechnology. The Rock and Tunnel network comprises everyone who works in the area within STA, and has an annual meeting. There is also a "small network", involving one representative from each business area: Planning, Investment and Major Projects, and this group meets monthly. These networks have a key role in external monitoring, for example they decide which conferences to attend. They are also important in initiating research projects and have a small budget for applied development projects. In theory, the business project leaders are expected to communicate experienced problems that occur in the projects to the specialists, who may initiate research projects based on these needs. This is however not common according to interviewees, since most project managers are not aware of the possibility to apply for research funds to solve problems.

2.4 Evaluation and implementation of research results

STA top management strongly emphasizes short term cost savings, and this is the primary focus for evaluating research projects. However, according to one interviewee it is only in about 20% of the research projects that results are implemented in business projects, and these are cases where there has been a clear problem and an identified and committed receiver of the results. It has been hard to find any cases where the cost savings expressed in the research application have been realized in practice.

Innovation in business projects in the Major Projects division is encouraged by a rule that each project shall save on average 3% of the project's total budget each year, without compromising the quality and environmental performance of the projects. The savings are verified by the Division's central units and published on a website as inspiration for other projects. This creates both a bank of lessons learnt and incentives for using it. Incentives for business projects to engage in more long-term research and innovation activities are however still weak, since new knowledge and innovations are seldom profitable in the first project.

In research applications, output is primarily defined in terms of knowledge dissemination: reports, scientific articles, seminars, etc. For each research project, there is a sponsor who is responsible for disseminating knowledge. However, implementation is seldom planned at the start of a research project and no resources are set aside. This is seen as an important obstacle to implementation.

An important way to implement research results is by updating STA norms, standard specifications and routines. Research results are frequently in the form of methods and designs which should be used by engineering consultancy firms or contractors, and the role of STA is to update standards and requirements to enable and facilitate the use of the new methods. The responsibility for such changes lies with the STA specialist units, who should interpret the research results and decide if and how to implement them. STA standards and norms are also mentioned as potential obstacles to innovation, but according to interviewees this is not an important problem in practice since rules are possible to bend if there is a good cause.

2.5 Culture and openness to new knowledge

The respondents were asked about the how important they perceived research and development to be within the STA. There were different answers to this question, partly depending on what part of the STA the respondents focused on. In this respect, rock construction was seen as strong area:

> "There is more emphasis in the underground area since the STA has a higher number of specialists in that area. We have many PhDs. And that, in turn, is because the client is always responsible for the underground conditions. It's not the same for other areas, although the STA has much knowledge in structural engineering. While in construction, there's only one Project Director with a PhD."

Further, higher management levels were considered to be interested in R&D, while the business projects were perceived to be less committed:

> "According to my experience [from other countries and industries] I can say that the ambitions on the top management levels have always been high here - there has always been much research in the Road and Rail administrations. But it has been difficult to reach all the way to the projects. In my view implementation is the biggest challenge. (…) One reason is that higher management does not understand how the projects are and should be controlled and managed. So there has been a mismatch between the two levels. What is exciting now is that the STA is trying to integrate the organization and close this gap."

The attitudes of the project managers were not seen as an important obstacle to engage in research, at least not in the Major Projects division, but rather that research activities are not prioritized compared with core project activities. Interviewees however explained that project managers generally lack R&D experience and do not know that the knowledge exists, or that there is STA funding for conducting research. Project managers also lack contacts with universities to start a research collaboration.

3 CONTRACTORS

3.1 Strategies, organization and drivers for engaging in R&D

The contractor interviewees emphasize that the clients decide to what extent the contractors will engage in R&D and invest in new technology. If the clients do not demand new technology, or open up for it, contractors will not be able to invest in, for example, new equipment. Thus, contractors closely monitor STA activities in order to identify future requirements. Today there is much focus on sustainability, especially reduction of climate impact. Also, the role of SKB (Swedish Nuclear Fuel and Waste Management Company) in driving development in drilling technology is emphasized, and SKB has a strategy for implementation. The trend towards design-build contracts is seen as important, since it increases the incentives to invest in R&D and hire people with higher competence.

However, there are other drivers for engaging in R&D, partly shaped by the funding agencies. One important organization is the Swedish Construction Development Fund (SBUF), which funds contractor-initiated research and development, often in collaboration with other funding parties (in rock engineering often BeFo) and individual clients or producers of equipment. The amount of co-funding the contractor company has to put in the research project depends on the expected delivered value to the industry. Thus, contractor companies may initiate and carry out research projects that benefit industry more generally, often as PhD projects in collaboration with university departments, without investing much of their own time and money. An important driver for investing in R&D is to be attractive as an employer, to both existing and potential employees:

> "Sometimes you may engage in development work and that's fun, but we don't do it to promote business but to keep employees who think it's fun. That the company is seen as being in the frontline in R&D signals, 'this is not a factory, you are allowed to use your head'".

Most of the larger contractor firms have a small central R&D unit with a very small budget compared to the total turnover of the company (0,5 % for one of the companies). Since funding arrangements typically require some co-funding in terms of either time or money, most research projects are initiated or supported by business projects is undertaken. As one interviewee comments:

> "We want R&D projects to be initiated by the business projects because then there are people who can participate. I have driven some projects centrally, but then there is a problem to market the results to the wider organization. There is no natural receiver, and if it is not exactly the right input for a project to solve an acute problem, it is hard to make use of the result. It's better if they have a problem and then we design a development project based on that problem."

Thus, it is easier for project level personnel to initiate research than it is for the central functions, which makes it difficult to define and pursue a centrally defined research strategy.

3.2 Implementation and internal knowledge dissemination

Adoption and wider implementation of research results is also highly dependent on if the contractor company itself has a business project where the new technology or method may be used at the time when the development project is completed. If this is not the case, the new solution will quickly be forgotten, even if it has been tested and proved to work. Further, contractor companies may invest in developing a method or technology, but although they often present results at industry seminars, they do not have a tradition of investing in actively marketing the product and producing professionally designed communication material. A consequence of the bottom up initiation is that research portfolios easily become fragmented and broad. This means that not all results can be implemented. According to one interviewee, the company has to identify smaller number of "cherries" to focus implementation efforts on.

The interviewees also mention that there are silos between business projects and divisions in the contractor companies, and that each project functions as an individual company. Knowledge is lost since the same individual or team seldom meet the same problem in their next project. Thus, there is a lot of knowledge in the organization, but no mechanisms to identify and use it:

> "As the former CEO of Skanska put it: 'If Skanska knew what Skanska knows'. The problem is that the knowledge is there, but when you need it you don't know where to look. We would benefit a lot just from mapping what we already know."

Both contractor companies focus more on implementation today than before. Skanska's R&D strategy from 2016 is related to the business plan. NCC has reorganized the management of R&D a few years ago, when R&D was separated from business development. R&D carries out long term research projects funded by EU and projects involving PhD students. A central development board has been established to approve and follow up large R&D projects. This is a way to increase transparency and control over these projects. Interviewees say that R&D projects were previously sometimes initiated without sufficient analysis. The business development projects are generally smaller and seldom pass the board. The initiation process is also less bureaucratic, but these projects need to show short term profitability. There is a system for suggestions from employees, but the experience is that it is challenging to evaluate large numbers of ideas and also to reward and act upon some of them.

In general, knowledge of individuals is seen as important, but strategies to capture knowledge from people retiring or leaving the company are not well developed. One interviewee complains that there are 20-year cycles in competence levels, since the companies are not able to retain knowledge over time but forget what they used to know when the individuals leave or retire. Both contractor companies have tested various database solutions for knowledge dissemination, but these have not worked as intended. However, following developments in IT new forms for knowledge transfer have been introduced, for example web seminars, and these have sometimes been successful. Another trend is to abandon the "people to document" model in favour of a "people to people" approach. This means that the company facilitates contacts between individuals with relevant experiences and knowledge, which provides more personal interaction and opportunities to ask questions.

Much of the external monitoring and knowledge dissemination is performed by the central specialist functions, who are involved in both research and business projects and facilitate learning between these two types of projects. There are internal company-wide specialist networks and knowledge centers, and especially within technical areas such as rock and geotechnology, contacts between specialists are frequent. However, interviewees note that traditional reward systems with bonuses etc. do not promote internal collaboration.

3.3 Collaborative research and immaterial property

It is hard to protect knowledge in construction. The respondents gave several examples where they had contributed significantly in the development of new technology that others had benefited more from. They also said that there is a limited number of specialists in Swedish rock engineering, and most people know each other and meet at industry seminars. In addition, academic research is public. There are different approaches to this problem: Skanska claims that since knowledge documented in reports does not spread anyway, it is better to be open and trust that those involved have a natural advantage. NCC tries to be more conscious about protecting what can be protected and collaborates with academia mainly in less applied R&D projects with longer time to implementation. One strategy is to communicate externally only those parts of the projects which are already well known. According to one interviewee, bad experiences are shared more willingly than new practices, at least to trusted colleagues.

When it comes to research collaboration with universities, direct research results are seen as less important than other kinds of output such as competence development, knowledge exchange, relationship-building and contacts with to future employees. The contractors have increased the number of PhDs over the last years and find the research skills and mentality of PhDs useful. This development is highly related to the availability of SBUF funding and was one of the reasons why the organization was initiated. Skanska and NCC have strategic goals for developing relationships to universities, such as stating number of adjunct professors or industrial PhDs. Several interviewees also mention the important role that the contractor companies have to provide access to sites for field measurements and demonstration.

4 ENGINEERING CONSULTANCY FIRMS

This section is mainly based on interviews within Tyréns, which is the major consultancy partner in TRUST, but also includes some information from a representative of another consultancy company involved in several TRUST reference groups.

4.1 Strategies, organization and drivers for engaging in R&D

For Tyréns, investing in R&D is an important strategic component to position the company on the market for premium engineering consultancy services, thus avoiding low cost international competition. The company is owned by a foundation and has a long history of investing in research: company profits are partly placed in an R&D fund. A few years ago, most research projects were initiated by individual employees based on their personal interests. The value of the project for the company was seldom defined and results were primarily disseminated in the form of reports and PhD degrees. The knowledge generated in the R&D projects stayed with the individuals, who, at a later stage, might move to a new position or even leave the company. Nowadays, Tyréns has developed a more strategic orientation for their R&D portfolio. They have defined a formal application process where all ideas have to be pitched to top management before applicants are allowed to submit a full proposal. The proposal is required to clearly identify needs and present a plan for implementation.

> "It used to be more generous but in recent years it has become more closely related to company value. (…) we talk more about implementation of projects, and we talk about taking the step towards innovation. Which means that we don't only do the R&D part and deliver a report, but also take the results to the market. And that applies to the PhD projects as well."

The requirement to test the new method or service on the market at an early stage also serves as a "Proof of concept": there is no point in spending resources to implement new knowledge more widely internally within the organization if there is no market demand. On the other hand, if there is demand, internal implementation is facilitated by this process. Still, the interviewees perceive that in-house R&D projects tend to come second to external projects with a clear customer and deadline for delivering results. This means that the research process often becomes inefficient.

The investment in R&D is also important for branding the company. For example, Tyréns has an innovation magazine, arranges high profile seminars for external audiences around their research results and produces web pages and product sheets. The company has also initiated an arena for open innovation with external partners, who can complement Tyréns with other competencies. The purpose of all such activities is not only to sell specific services but also to communicate the company profile. This is a change in mindset; the tradition has been not to put money in implementation. Tyréns is now planning to work more with formal marketing plans and communicate research projects early in the process, even before the results have been obtained.

External communication has first priority, but internal communication and implementation also comes high on the agenda. This is important, since more people have to be able to sell the new knowledge in order to increase sales. Meetings and the intranet are traditionally the main vehicles for internal knowledge dissemination, and there are several types of regular meetings for this purpose. In addition, internal specialist networks in different areas are often small in the consultancy firms, for example only about five in the geo-thermal group, so it's easy to keep each other informed.

An interviewee from another engineering consultancy firm says that his firm does not focus as much on R&D as Tyréns does. In his company, there is a Knowledge and Innovation Director for the Transport Division, but no organizational unit. The respondent is responsible for knowledge development in his specialist area, and can put 10% of his time to participate in R&D projects, often in reference groups. The Division also has a small budget for R&D projects from which the employees can apply. The projects should have a potential to generate profit for the company. The Division has a general R&D

strategy but no specific routines or instructions. Hence, the specialists themselves define the actual strategy:

> "The company is not involved in this project, it's me. Then that I'm allowed to do it, that's a good thing. But it's not a company strategy."

Another way of funding research in this consultancy company is in successful business projects: if there is both a need for new technology and enough money generated in the project an R&D project may be initiated. The respondent however also says that the company wants to be perceived as an important and innovative actor, and that there have been some very ambitious innovation projects. Nevertheless, he does not see any relationship between these company-level initiatives and his own research activities such as those in TRUST: "These are kind of two different worlds".

4.2 Collaboration with academia

Collaborating with universities is seen as essential in order to be in the front line. Another value of collaboration between academia and industry in applied research is that industry actors can boost implementation by matching new knowledge with real world situations:

> "I have the direct contacts with construction projects and can see immediately what the researchers can do in a project and then I can connect them, it's incredibly powerful."

According to another respondent, this direct contact between research and practice implies that he can suggest testing methods developed in research projects to his own customers, and then bring problems or data from these projects to be analysed in research projects. This way, implementation becomes highly related to the commitment, competencies and relationships of individuals.

According to one interviewee, collaboration with academia is however not always easy, since universities and companies have different goals. This may create conflicts between those who have only worked in one of these worlds, and to bridge this gap it is important that individuals with PhDs start working in industry or society. The number of PhDs in consultancy firms has increased over the last 15 years:

> "When I started in 2002, I was the fourth person with a PhD in the whole company. Today, there are seven PhDs out of 30 people only in my department. This is not representative for all parts of the company, but there is a considerable increase overall."

Much of the value of the R&D projects are considered to be the individuals that develop knowledge of both technical subjects and of the culture and business model of academia. Nevertheless, it is also believed as important that these former PhD-students, maintain relationships to research, often with former colleagues and supervisors at the university they came from:

> "Today, we are trying to find ways for people to keep one foot in research, perhaps by supervising a PhD student."

5 VIEWS ON INNOVATION PROCESSES AND CULTURE

5.1 Factors affecting innovation level

Many respondents agree that knowledge development in underground construction and rock engineering has previously been slow. At one of the TRUST workshops, a contractor design manager presented an analysis of the development of Swedish rock tunnel design and construction in the last 40-50 years, and concluded that innovation had been rather limited over this period. Several interviewees mentioned a general conservatism among practitioners in a sector where ocular inspections and expert assessments have traditionally been favoured before theoretical models. One view was that many engineers active in underground project are negative towards research and research-based knowledge. These individuals try to find reasons not to believe in scientific results:

> "They say that 'well, it was a very dry spot where we tested Silica Sol'. So even if it worked when Chalmers tested, that was only because it was a dry area."

However, this culture is perceived to be changing, much due to increased levels of education and a generation shift in the industry:

> "This is very much on its way out, but it's about dominant individuals being sceptic about various subjects. I wouldn't call it a macho culture, it's more a general contempt for knowledge and research that has been allowed to dominate. And one cause of this cultural problem is that we didn't build any large infrastructure projects during the 1980s and 1990s. So a whole generation never entered the industry, and one effect is that we are backward in many areas."

Another aspect mentioned is that there have been a few especially challenging projects such as the Hallandsås tunnel and some Norwegian projects, where people have been forced to look for new knowledge. Accordingly, industries acting in areas where the geology is more complicated or in active earthquakes zones are believed to be better at absorbing and implementing new knowledge. Clients and companies working in countries such as Sweden and Norway with good rock conditions do not have the same needs. Another factor is knowledge spill over within a region or country: Denmark has a lot of geophysical expertise within groundwater, and these individuals and firms use their knowledge in other fields. By contrast, groundwater research in Sweden was mentioned as an area where development is slow.

Individuals may also influence the innovation climate and methods used in the region where they are active. For example, geophysical methods are used more in the south of Sweden (where the researchers responsible for TRUST projects 2.1 and 4.2 are active). However, according to one respondent these differences have diminished over time, as the research environments in different regions in Sweden have started to collaborate more. Nevertheless, one interviewee from the Stockholm region said that geophysical methods are still employed primarily in research and not considered to be standard methods in business projects. There are two ways of implementing change, he said:

> "Either you negotiate with several projects one by one to be allowed to test and evaluate the technology. And eventually you have developed a strong repository of experiences that is sufficiently convincing. Or you make a more substantial effort to develop a viable method that can become standard and thereby create an acceptance in a shorter time."

A new technology may develop and there may be a technology push, such as is the case with fiber optics, BIM and new ICT making it possible to generate and analyse large amounts of data. New opportunities may also arise when existing technology becomes cheaper and therefore more available for this industry:

> "In the geophysical area, development has been driven by the oil industry. They have had much money to develop new technology but have not spread the knowledge and also the

> technology has been too expensive for us. But now a lot has happened in a very short time, it is quite exciting, there is a whole new world that has opened up."

One respondent with experience from performing research in other countries did not think much of the Swedish innovation climate in this area:

> "Sweden is very conservative – it takes ages to convince companies. It seems that everyone is waiting for others to test, and most will wait until everyone else uses the technology. This is different from Canada and the US, where companies are much more willing to test."

If the BeFo program committee sees a need for more applied development work to drive implementation of a promising new technology they may issue a specified call in that area, sometimes a joint initiative with the STA. Examples of such initiatives are the development of standard models for road tunnels and multi-hole grouting technique. Consultancy companies are often involved in such development projects. Contracts are seen as extremely important obstacles to the development and implementation of new methods and technology in the sector, and especially in combination with public procurement regulations. One aspect is that contracts hamper site-based testing and measurements, since it is hard for contractors to assess the effects of research on construction processes and price them in a tender. Traditional contracts, where the client engages consultants to develop the detailed design, also impede development since new untested methods cannot be specified in the tendering documents. Design-build contracts may solve this to some extent, but not completely. Another option is collaborative contracts, where contractors are involved earlier in the process. In some cases, such as with multi-hole grouting, the STA have changed their standard procurement requirements to open up for such methods.

Contracts also act as obstacles for consultants to engage in innovation since they are not paid to investigate several alternatives. Here, fixed price contracts can potentially open up for innovation, but interviewees on the client side see few signs that consultants will invest in developing new competencies in one project to be able to benefit from these investments in future projects.

5.2 Implementation of research results

Both consultants and contractors emphasise the role of STA in shaping the incentives for innovation in the sector. It is however perceived as difficult for external players to influence the STA:

> "STA is a really important actor, by far the biggest procurer of geotechnical investigations. And all the years that I have been active in the geotechnical committee, which is at least ten years, we have tried to get into their meetings for all geotechnology staff (teknikdagar) to present new methods and standards for geophysical investigations, but we haven't succeeded once."

One view is that the STA as an organization is not equipped to lead the development in the geotechnical area:

> "The STA are 6000 people and they reorganize every second year. And they are responsible for everything, from small everyday operations to the really big projects such as Stockholm Bypass. And that's too much. There are good people working at all levels, but they are not able to make decisions and they don't know who is responsible for different questions. (…) If you take my field, they have 30 specialists in geotechnology, and they don't have the time or any responsibility to implement new technology."

The researchers perceive SKB, a much smaller organization managing the Swedish nuclear and radioactive waste, to be easier to collaborate with. However, they also acknowledge that the situation is much more complex for STA, since this organization has such a wide responsibility:

> “There is so much that we don’t understand about their issues and problems, we think that we understand but then there are a couple of other layers. Such as secret tunnels, sustainability and acceptance from society. They are part of a complex puzzle, while SKB can act within their cube and no one disturbs them.”

As one respondent argued, another aspect that may potentially hamper implementation is the strong academic orientation also among the industry representatives involved in research. They may engage in a project because it is interesting and promising from a technical point of view and are perhaps not aware of important practical aspects affecting the implementation context:

> “Implementation is seen as important, but either there is some kind of mismatch or failure in conceiving more in detail how implementation is supposed to happen, or there is not enough resources invested. Geophysical investigations, for example, have to be performed in a specific phase in the pre-investigation process. And for a new technology to be implemented, this requires that the project managers and the project level procurement functions are aware of the new methods.”

5.3 Knowledge dissemination through networks

Professional networks are seen as extremely important for knowledge dissemination and exchange. Some broad networks were considered to be central by all interviewees, but each interviewee also mentioned several smaller and more specialised networks. One of the most important networks is related to the Swedish Rock Engineering Research Foundation (BeFo), where specialists from different organizations meet in the program committee to prioritise between research projects. As one respondent said:

> “Communication is really easy – decisions never involve anyone who is not part of the BeFo program committee.”

On the other hand, another respondent remarked that the standardisation committees, except for Eurocode, are not well connected to the industry networks despite that the committees have a great influence on practice. Other important networks are Swedish branches of international professional associations, e.g. the Swedish Rock Mechanics Group is part of the International Society for Rock Mechanics. These associations organize annual seminars, which are central to networking in their respective areas, for example seminars for rock mechanics, groundwater and grouting. Within the larger networks, there are smaller, specialised communities:

> “The networks in engineering geophysics encompass about 15-20 people in Sweden, and it’s hard for a specialist not to be part of them. The networks are open and changing: new people enter others disappear for a while and perhaps come back. People know each other also on an international level and it’s easy to start collaborations.”

In addition to professional networks, interviewees say that large construction projects may form the basis for knowledge development and dissemination. Not all large projects take this role; it depends much on the attitudes of the project managers and specialists involved. Furthermore, relationships between former PhD students and the university environment where they graduated are important informal networks that often form the basis for initiating joint R&D projects.

6 INNOVATION AND KNOWLEDGE DISSEMINATION IN THE TRUST PROJECT

This section discusses innovation and knowledge dissemination in relation to TRUST, primarily based on interviews with responsible researchers' part of the TRUST alliance. In 6.1 – 6.6 we outline the background and implementation aspects in relation to five of the TRUST sub-projects. In 6.7, we describe more generally the motivations that the researchers express for communicating research results and collaborating with industry and society.

6.1 Background

The TRUST alliance comprised ten projects of which eight were able to receive funding, see Figure 1. Co-funding came from the industry, either in cash or in kind. Two industry organizations provided most of the cash co-funding: The Swedish Rock Engineering Research Council (BeFo) and The Swedish Construction Development Fund (SBUF). BeFo engages representatives from clients, consultants and contractors, while SBUF provides funding to contractors. Both organizations have boards and groups responsible for reviewing and selecting applications. Often, they require that the companies that are involved in the proposed projects contribute with in kind resources and cash.

The aim of the alliance was to establish a collaborative arena to develop and implement methods and technology for the entire process of planning, design and construction of urban underground structures. The idea was initiated at a matchmaking meeting organized for the Geo-Infra call, and the leader of the Geo-group in the national collaborative organization Swedish Universities of the Built Environment led the work with the joint application and became the project leader of the umbrella project. However, the projects applied for funding individually and two of them did not receive funding from Formas. The TRUST project was divided into four parts (see Fig. 1): 1. Management (including innovation), 2. Pre-investigation methods (4 subprojects, 3 funded), 3. Underground construction methods (3 subprojects, 2 funded) and 4. Information models, data structures & visualisation (2 subprojects). An important feature was that the different subprojects would perform investigations at a joint physical site. This would allow different pre-investigation methods to be compared, and the data could be brought into a common geo-information model for visualisation and joint interpretation.

The Management subproject comprised coordination of research activities, supporting collaboration between the research teams, and initiating discussions about implementation aspects. For these purposes, monthly telephone meetings and biannual workshops were organized. Within the management project, one part was further devoted to investigating and following up implementation processes in relation to the subprojects by means of interviews and workshop activities. This section presents the results of this subtask.

All projects were relatively close to application. Implementation conditions and type of output differed between projects: some projects were developing new technologies that can implemented as product innovations – such as new surveying geophysical instruments and methods and improved grouting rigs. For others, results could potentially be implemented in the form of a policy or a standard, or as methods for joint interpretation and evaluation of different site investigation methods.

6.2 How were the sub-projects initiated?

In general, researchers emphasised the role of previous relationships in initiating research collaborations. A call from a funding body in an area where there is an already established network is perceived as an important prerequisite. For example, project 2.1, about geoelectrical imagine for investigating of contaminated soil, was a continuation of a previous project in which many of the participants were involved. When the GeoInfra call came up, these met to discuss a possible future collaboration, also involving some more people who had been talking about collaborating.

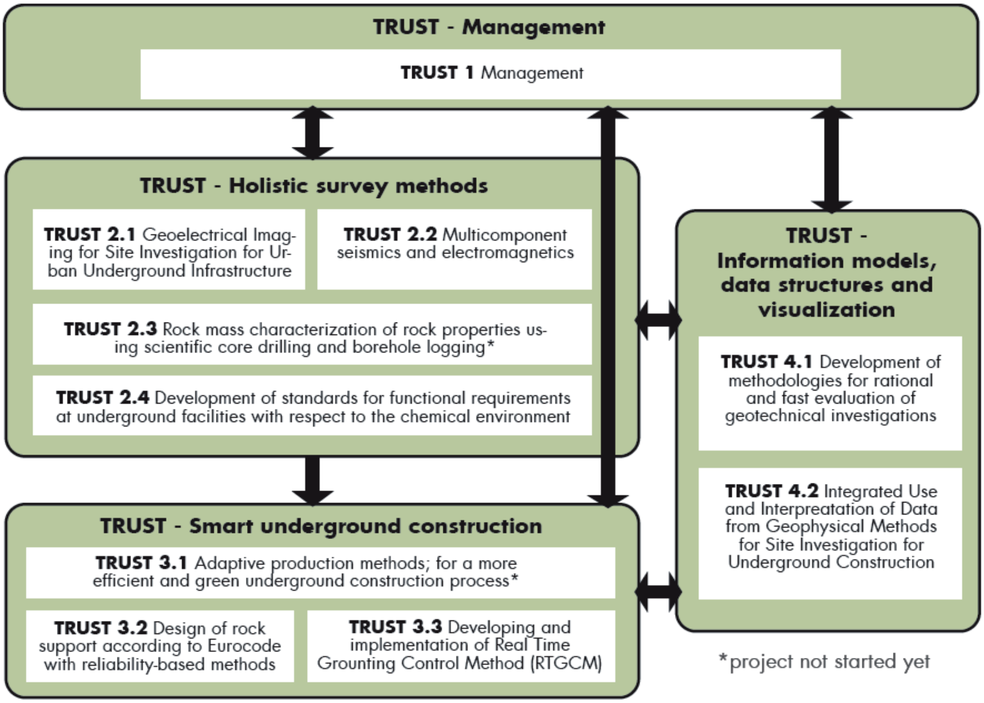

Figure 1: Overview of the TRUST projects. Project 2.3 and 3.1 did not receive funding and therefore never started.

Some projects had indirectly a very long history, especially 2.4 could be traced back to research by the project leader on acidification effects on water in rock in the 1980s. This particular project was however initiated at the matchmaking meeting organized by the research council Formas, with the aim to provide opportunities to present and find partners for the research proposal. At this meeting, representatives for research institutes with lab facilities approached the project leader to suggest a collaboration.

Project 3.3 was based in a long-established research on grouting and the RTGC model that has been going since the 80s, when two key individuals at KTH and Chalmers started to work in the area and successively developed theoretical models and methods. Over time, 16 PhD candidates have graduated from their groups and many of these are involved in the TRUST project.

Project 2.2 was also based in a previous project, where the idea of the "landstreamer" equipment for geoseismic investigations was conceived. They wanted to test the equipment but since they had previously mostly done basic research, they did not have the industry partners needed. Also, while the other research environments involved in TRUST knew or knew of each other and had been discussing collaboration within the national collaborative organization Swedish Universities of the Built Environment, the group responsible for project 2.2 was new to most of the others. They were brought in by the TRUST coordinator, who had met the project leader in a previous project.

Project 4.1 consist of two parts, the development of the GeoBIM concept by a group from Tyréns and research on joint interpretation and evaluation of the reliability of different site investigation methods using statistical analysis by KTH. The KTH and Tyréns researchers met at the GeoInfra matchmaking event and decided to team up and write a common application, where the funding from Tyréns was used as industry contribution to match the funds coming from the GeoInfra call.

Project 4.2 was initiated already before the GeoInfra call was issued, including some funding. When applying for more funding from SBUF, they were recommended to apply to GeoInfra.

6.3 Finding co-funding

Since co-financing from industry was a pre-requisite for funding from the Geo-Infra call, the cooperation with industry has been essential to initiate projects. Industry partners were most often involved at an early stage. These linkages and networks have generally grown over time and are often established during doctoral studies. For example, many of the graduated PhD in grouting and RTGC (project 3.3) from KTH and Chalmers now work in the industry and governmental organizations such as STA. Project 4.2 did not receive GeoInfra funding, but in the end was granted SBUF funding anyway.

Project 2.4 was granted research funding from GeoInfra, but it took a long time for this project to find the co-funding required. In the end, the project involved cash co-funding by four additional funding agencies, apart from the in-kind resources provided by the research institutes and one contractor company.

Project 2.2 as well had difficulties finding co-funding. They attended the matchmaking event, hoping to find potential industry partners, but there was no success. However, after the project was funded by Formas, BeFo, SBUF and some companies agreed to provide co-funding.

Knowing that the GeoInfra call was a large scheme that would require substantial co-funding, the contractors' funding agency SBUF asked researchers to submit their preliminary proposals and gathered its industry advisory board to review them and prioritise them. Thereby, researchers could get an indication of the opportunities to receive co-funding from this agency. However, SBUF as well as Formas and some of the other initiators of the GeoInfra call had expected to get more new collaborations, for example combining architectural, technical and behavioural aspects of underground planning and construction. Instead, they to a great extent got the "usual suspects", with established networks.

6.4 Planning of dissemination and implementation

Most interviewed TRUST projects planned their dissemination through traditional channels such as seminars, scientific conferences and publications. BeFo regularly requires an implementation plan and presentations at broad industry seminars. Meetings and workshops with the appointed reference group and other involved stakeholders (co-funders) were opportunities for dissemination of result. When there is a long history of collaboration and BeFo-funding, this model is so established that it is taken for granted:

> "We didn't discuss the communication of the results in addition to the dissemination that occurs naturally within the network and to other BeFo members" (Project 3.3)

> "In most applications it says "a presentation at the annual rock mechanics seminar and conference papers" (BeFo)

In 2.1, the project discussed implementation when planning the project, taking care to involve potential recipients early on in reference groups. Several full-scale demonstrations were performed within this project. Project 2.4 also planned for implementation early on: the project leader in contacted experts on STA to investigate how the result could affect the STA standards as a way to implement the results. These experts were part of the project leader's university-industry-government network from the time they took their PhD degree. Both 2.1 and 2.2 made youtube films to spread results. In project 4.2, knowledge dissemination was less planned initially than in 2.1, despite that the leading researcher was the same. Still, dissemination activities in the project were extensive, but the strategy was developed over time and led by the consultant partner.

In 4.1, where the consultancy company Tyréns had an important role, much resources have been spent on communication, internally as well as externally. There was an explicit intention early on to focus on communication, but no formal communication or implementation plan was developed. Instead, activities unfolded over time as each communication event yielded requests for additional seminars and presentations for other audiences. The early communication has meant that the new concept has spread within the company and been applied in so-called pilot test in other on-going Tyréns projects before being completed. These projects have served as showcases for further dissemination. One respondent said that one thing he has learned from TRUST compared to previous projects that it is essential to communicate over and over again, not just once.

6.5 Outcome, implementation and recipients of innovation

The projects have different outcomes and key recipients in the project supply chain:

- Projects 2.1, 2.2 and 4.2 specifically target design and engineering consultants by providing better algorithms and instruments for characterising the underground. These methods and instruments need to be implemented by suppliers of geophysical instruments and software and used by the consultants doing the geophysical investigation.
- Project 2.4 develops knowledge of the effect of acidification of groundwater on underground infrastructure (e.g. corrosion, concrete impact and hydrology). This knowledge can be implemented as regulatory requirements or recommendations in procurement of construction and maintenance of underground facilities; hence, STA was identified as the key recipient.
- Project 3.3 is about validating the Real Time Grouting Control (RTGC) model to adapt the grouting pressure after rock conditions. The key recipients are the clients and contractor. In a design-bid-build contract the client determines the grouting model, whereas in design-build or turnkey contracts the contractor decides this.
- Project 4.1, the GeoBIM part with its tool and database organizes all geotechnical data (including contaminated soil data from 2017) in a project or an organization. The GeoBIM is implemented in approximately 10 projects and/or organisations (Nov 2016).

Several TRUST projects were successful in terms of implementation, although this was often the results of a long process started before the TRUST program as initiated. Apart from the Tyréns project 4.1, there were two areas where the increase in implementation was significant during the time period of the TRUST programme: geophysical methods and grouting based on theoretical models. In both cases, development was based on a combination of new research results and availability of skilled personnel, primarily PhDs, in the industry. Within grouting, the main development began to take off before the TRUST projects, while two of the TRUST projects jointly contributed to a very recent boom in the application of geophysical methods. The project leader for the grouting project (project 3.3) described the implementation background in the following way:

> "Research in this area has been going on for a long time and the total investment is high. Now people expect some results, this is a must after all these years and there is some criticism that it has taken this long. The reason is that the funding bodies have invested in small portions, we get a million each time. So, it is not until now that there are sufficient results. And of course, we could have had results earlier if there had been a big program, but then we wouldn't have had 18 ex PhD students to take care of the results and implement them." (Project 3.3)

The projects in TRUST are part of the support infrastructure that provides knowledge to the actors in the project supply chain and the regulatory and institutional infrastructure. In Figure 2, the projects are positioned in a model of knowledge flows adapted from Gann and Salter (2002). Government organizations (STA, SGU) were perceived as key recipients to target, since they can legitimise a new technology to other parties. Most interviewed researchers pointed out the strong influence that the client, as the main beneficiary of the results, has on implementation of innovation in the construction supply chain. However, consultants were also identified as a key recipient:

> "First we need to convince the consultants to use the new technology, and the consultants then need to convince the client".

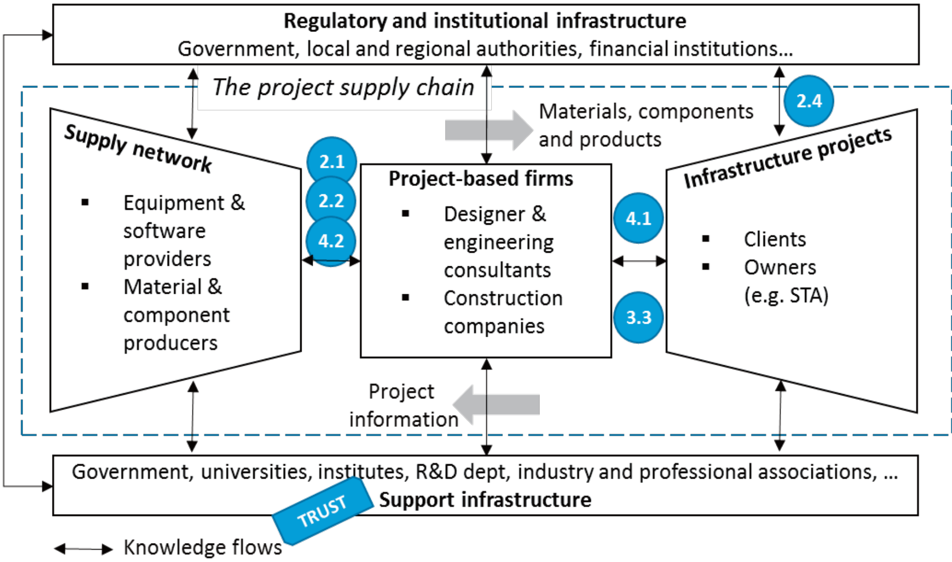

Figure 2: Knowledge flow between academy and industry in underground construction in relation to outcomes of the TRUST projects, adapted after Gann and Salter (2000)

The development in STA and other client organizations towards a lean client function, which is no longer supposed to specify methods for pre-investigations, only the results, also implies that the consultants play an increasingly important role. This is something that the researchers are not always aware of:

> "Initially, we approached the Swedish Transport Administration, but it was clear that they buy this kind of services from consultants".

More generally, the importance of individual champions and gatekeepers was emphasised:

> "It is important to reach the right person, there are always people in organizations that are open to new technology, new methods and so on. If you can reach out to them and demonstrate that this is something that can really be useful, really provides additional value. Then you can convince also those that are more skeptic that it might be worth testing."

Although many of the researchers felt that they had good knowledge of key recipients and when in the process their output had to be implemented, especially PhD students and the younger researchers with little practical experience were less aware of implementation aspects more in detail. At one of the workshops, one of the TRUST consultant members held a presentation explaining the planning and building process in order to clarify which parties would need to be targeted in order to implement the results from the TRUST sub-projects, and at what point in the building process.

6.6 Obstacles and drivers for implementation of results

The interviewed researchers from the different projects were asked to comment on possible obstacles for the outcome to be put to use. They could provide free answers but were, if interview time permitted, also asked to indicate the importance of a subset of categories defined in the innovation system literature. See **Fel! Hittar inte referenskälla.** for a summary of answers.

In sum, relevance and existing sunk costs were not perceived as important obstacles to putting TRUST results to use. Lack of researcher resources and incentives for knowledge dissemination could be a problem, primarily because funding is short term and the priorities of funding agencies change. Thus, when a project is finished the researchers are busy starting up something else within a partly new area. However, one researcher also said that too much communication could be counter-productive: “You should not push too far and allow for the ideas to mature”.

The most important obstacles were related to recipients lacking skills and needs for new standards and services. Legitimacy could be a problem, also after the method had been validated. The level of investment varied between projects, and higher costs could be an obstacle even if quality was higher. Demonstration and test beds were perceived as important, but such tests had been carried out or were planned in most cases. Still, it was perceived as difficult to arrange tests on constructions sites during production, also for those with very good industry contacts. Other obstacles to implementation mentioned were conservatism, authorities’ inertia and the lack of knowledge transfer from project to project.

In the next table, Table 2, the main drivers for result to be put to use are listed. Here, most of the drivers mentioned were seen as important. However, since projects were still ongoing actual implementation was in several cases a future issue and assessment of drivers partly hypothetical. Respondents tended to focus on explaining the importance of their results as potential drivers. The main driver to look for new solutions was perceived to be when a critical problem occurs in a construction project. In such situations, researchers are frequently called upon to perform measurements using new technology. This was the case in the Hallandsås project, where new technology for rock characterisation was tested and found very useful. Such ad hoc commissions were however not always easy to handle for the research community, since they cannot be planned for.

Interviewees also emphasised that much depended on individuals, and that commitment of one or a few key individuals at key positions could have a strong influence. For example, those responsible for STA standards were mentioned as important gatekeepers. That there are people with a research background in industry and authorities was seen as essential to implement new technology:

> “We need our people to talk on the other side. Key individuals are always important. Somebody has to take the risk and commit the company.”

However, not all industry project participants were equally engaged:

> “The level of interest differs between the members in the reference group. Some of them are very active, they think it’s really exciting and propose new ideas etc. While others mostly sit and listen and comment occasionally.”

Individual commitment to implementation and an entrepreneurial orientation on the researcher side was also perceived as important:

> “Engaged researchers develop more practical results and some of them have a personality that makes their projects more visible, their teams more visible, and it is easier for them to have their things tested in practice. And therefore, their research is more likely to be

implemented. (…) I think that you get better results if you can communicate and be visible, because it leads to better feedback than if you sit in your room for 4-5 years before presenting the results." (BeFo)

Table 1: Perceived obstacles for the use of the result from the TRUST projects

OBSTACLE	PROJECT 2.1	PROJECT 2.2	PROJECT 2.4	PROJECT 3.3	PROJECT 4.2
Weak legitimacy	Depends on region	No, everybody agree that this is better	No	To a small extent, but natural since the method has not yet been validated	No
Results do not relate to problems as perceived by users	Users need to be informed	Easier to convince in high risk projects but would be useful in medium risk	No	No, but clients benefit more from cost savings than contractors	No
Recipients lacks skills	Yes, usage require equip., software and skilled people	Yes, the technology requires some new skills	Yes, civil & rock engineers lack skills in this field	It requires some training of client & contractor	Yes, but also easy-to-use interface to make it easier for end user
Return on in-vestments is unclear	Yes, benefits relative to user costs are unclear	Yes, 50% more expensive but higher quality of result	No, modest investment, mostly training	No, investment small relatively large cost of grouting	-
Result make already made investments obsolete (sunk costs)	No, method is an addition to traditional drilling	No, this is an addition not a replacement	No, appl. adds value and skills to user	No	-
New standard or service need to be developed	Yes, but first more research and user interface development is needed	Yes, better standards on consulting services	Yes, this is the whole point of the project	Yes, to some extent	Yes
Demonstration projects and testbeds are needed	Yes, to show usefulness of method	Yes, but this has already been done by several comp.	Yes, but demonstration test is included	Yes, we have labs but need to test in real environment	-
Lack of incent. or resources to disseminate result to users	First, a better theoretical understanding is needed	No, we have sufficient resources	Yes, increased resources are desirable	No, important recipients are familiar with the result	No, it will be more difficult to find resources to develop the prototype

Table 2: Perceived drivers for the use of the result from the TRUST projects

DRIVERS	PROJECT 2.1	PROJECT 2.2	PROJECT 2.4	PROJECT 3.3	PROJECT 4.2
Users are actively looking for better solutions	Yes, problems acknowledged but users are not active yet	Yes, especially in problematic geology where risks are high	Yes, problems acknowledged but users do not understand	Yes, cost of grouting is high	Yes, to better save money and environment
It's important to demonstrate the result	Yes, to show that this method is better than conventional drilling	Yes, we have to produce useful knowledge	Yes, this project should generate knowledge to society/industry	Yes, definitely it is expected that useful results will come out	-
Industrial partners want to apply results commercially	Yes, equipment manufacturers and consultancy companies	Yes, industry partner markets skills/connection to customers	No, not really. Contribution to society most important	Yes, but primarily with clients	-
The area is under debate and politically hot	Yes, politicians more aware that contaminated sites are a major env. problem	No, not politically	Partly – the result is about lifespan and durability of our infrastructure.	Yes, due to high costs associated with infra projects	Yes, the environmental demands are increasing
New available tech. creates technology push	Yes, developments in IT have been important	Yes, develop. is based on new fiber optics	No	No	Yes, developments in IT made the project possible
Demand from users for new knowledge, tech or methods	Yes, better methods to detect contam. sites are needed	Yes, to mitigate risks	Yes, but mixed response from clients and industry	Yes, to some extent	-

6.7 Researcher opinions on drivers and incentives for collaboration

Interviewees highlight several drivers for the academy to collaborate with other researchers, users and industry. First it is a question of access to resources, both personal, equipment and financial resources.

> "The problems are so complex that no one can have all the knowledge needed to solve them. We need to collaborate with other researchers, industry and society in general to understand the whole picture.
>
> "There are driving forces such as training, lab opportunities, etc. that you can share"
>
> "It is absolutely necessary to collaborate with industry in order to finance the research. We do only applied research. But we rather work with industry than with grants from the Swedish Science Foundation."

In effect, to be applied and make an impact on society was perceived as important to all researchers. Many examples of research results that had been implemented in practice were provided, but these had generally not resulted in patents or revenue for individuals or the university. As one interviewee expressed:

> "We are really applied here. You can see it in my PhD project, I developed a prototype for a measurement system that later became a multielectrode system that is used worldwide. So, there was a good application of that research. And there are other examples. [mentions projects in georadar and geothermics] Much of what we have done has gained a high impact."

Collaboration was seen as a question of contributing to society and getting feedback that you are doing the right things:

> "To feel that you are contributing to solve a real problem in society. This is our main driving force"

> "You have a communication with society and the recipients all the time, because it would be really boring if we didn't."

When asking researchers about what benefits they believed that industry partners perceived in the collaboration, the following drivers were discussed:

Direct application of the results: Some research results can be directly implemented, especially by instrument developers and consultants, which can develop more competitive products or services to customers. More advanced survey technologies can also minimise project risks for clients and contractors. However, although usability of results is believed to be important, researchers said that industry partners understand the PhD process and normally do not have high expectations for directly applicable results. According to the researchers this was beginning to change, so that especially some consultancy companies are more interested in the direct results. The researchers approved of this development. According to the BeFo Director, BeFo as well is becoming more focused on implementation, although there is still an understanding that a research process is uncertain and that the result is not always what you expected.

Maintain university environments as a basis for training in the field: This was not believed to be so important by some researchers' but very important by others. Knowledge transfer between academy and industry was in some cases substantial and sharing of personnel resources for guest lectures and adjunct staff from the industry performing research tasks and PhD supervision was common.

Training of doctors that can be recruited: Recruitment of PhDs was believed to become more important with increased globalisation. In some research subjects 40% of the PhD students are employed by the industry also during the PhD work, so called industrial doctoral students. The importance of having educated PhDs in the companies was also emphasised, since these understand the conditions for research.

To participate in the arena of shared learning and knowledge exchange: This was believed to be important by all. Other arenas were also mentioned, such as SGF that provides courses for professionals.

To be perceived as an innovative company: For some companies (Tyréns) but most companies do not actively use it in marketing.

Build relationships for the future, personal interest and commitment of individuals: The commitment of individuals was seen as essential to build networks between the academy, industry and public organizations.

7 THE TRUST COLLABORATION – PROCESS AND VIEWS

This section briefly outlines the TRUST collaborative process and the experiences gained.

7.1 Background

An important goal when initiating the TRUST collaboration was to be able to take an holistic approach to ground investigation data and resources:

> "Our experience is that data are forgotten. If they have done seismic measurements in an area at one time, this costs a lot of money but when this investigation is finished the data are not saved despite that they might be needed later. Instead a new expensive investigation is performed. (…) There is also much to gain by planning and coordination of measurements. For example, the holes resulting from drilling for samples to analyse cracks can also be used for rock tension or water chemistry measurements. Today the focus is on getting perfect samples while the holes look like shit, but this is only a question of how the drilling contractor is contracted."

The idea of a collaborative project was supported by the funding agencies and the industry, who thought that it would be a good idea that researchers collaborate instead of competing in a small country such as Sweden. It was however not evident for funding agencies to support the management project:

> "This umbrella, called the management project, and which we have funded separately, was much discussed within BeFo since it is not technology but more about project management. But we ended in a decision that we could promote the values related to innovation and implementation, which are issues that we see as very important but very difficult."

As already mentioned, not all projects planned to be part of TRUST were funded. Thus, some areas in the holistic approach were missing, such as the relationship between rock mechanics and geophysics and the relation to construction methods. Another area that became problematic was the joint test site, where different methods could be combined and compared.

7.2 Finding a joint test site

In early contacts taken by researchers, high level STA technical managers within the BeFo network envisaged that TRUST would gain access to a major road tunnel project that would be starting construction at an appropriate time, the Stockholm Bypass project. Thus, the researchers started to investigate which parts of the tunnel stretch that would be most suitable as a joint test site, also considering the GeoInfra focus on complex urban environments. However, getting access to the project turned out to be more difficult than foreseen. First, the road tunnel project was delayed in the planning process due to political reasons, as the Swedish green party attempted to stop it when they became part of the government after the 2014 elections. When the project was restarted the tendering process was already planned and could be initiated promptly. The STA construction project director then stated that it would be impossible to perform new geotechnical investigation during the time period of tendering, since this would result in new information coming out that was not in the tendering documents. The TRUST management team approached the STA to find alternative sites, but there was little response. In effect, there were few projects in the right stage and suitable geographical location. Thus, some TRUST projects started investigations at other sites where they could get access, while other projects were delayed. Eventually a solution emerged as the organization SKB, the Swedish Nuclear Fuel and Waste Management Company, was looking for a partner to continue operating their existing test site at Äspö, close to a nuclear power plant north of Stockholm. However, the problem with especially urban tunnels is often that rock coverage poor, while the Äspö test site was deep and undisturbed. Still, advantages were considerable, and the TRUST management grasped this opportunity.

Thus, the size of the TRUST project turned out to be a disadvantage when it came to testing, a difficulty that was not expected by the STA specialists involved in the project.

7.3 STA involvement and implementation

In general, it turned out to be hard to establish a viable model for the collaboration between STA and the TRUST project. Normally, there is one personally committed STA specialist responsible for each research project. In the TRUST case initial contacts were taken primarily at higher levels in STA and there was also a central, senior STA representative as a contact person for the TRUST management team. As an STA person not directly involved in TRUST said:

> "It is good to have broad collaboration, it facilitates implementation. More people involved from the STA makes it easier to coordinate and commit resources. It also becomes easier to identify which people to target in order to get the necessary approvals."

However, although there were STA representatives involved in some sub-projects, it was primarily a top R&D manager who participated, and he could not devote sufficient time to the project. He explained that:

> "There is a problem that no one in STA has the time to work with TRUST. We should have more resources, but the specialist functions are consumed by the projects who have a short-term need. The organization does not see the direct value but participates more to support research."

Thus, the main STA responsible concluded:

> "Broad collaboration such as that in TRUST is no advantage for the STA – it is hard for us to commit enough people. It easily ends up so that the STA economises so that one person takes care of the whole TRUST project instead of assigning one person for each subproject."

Thus, despite that STA was a primary recipient for this kind of knowledge in TRUST, they were not perceived to be active in implementation. Another TRUST member summarised how the other participants perceived the role of STA in TRUST:

> "The STA is one of the organizations that are behind GeoInfra. They saw a need: there will be a lot of rock engineering projects in the future, there is a need for R&D in this area, there is a need to increase efficiency. And then I think that many of us perceive that when the research project starts they disappear … they put in money but are not active and involved in implementation."

7.4 Collaboration between research projects

Planning for collaboration

An important aspect in the TRUST project has been to enhance collaboration between the research projects. This issue was brought up at the first joint workshop in February 2013, and project members decided to use inspiration and tools from partnering in construction projects. Such tools include development of joint goals, documenting them as a "Partnering Declaration", and follow-up workshops. This process was supported by the researchers in the TRUST management project. In the two workshops in 2013, partnering methods were introduced and the researchers worked in groups to discuss potential synergies and risks associated with research collaborations. Discussions were held in four groups: General collaboration issues, Data sharing and quality, Publication and impact on the research field and Impact on society. The results are summarised in Table 3.

The management group developed a draft Partnering Declaration based on the group discussions, and the draft was further refined during the monthly telephone meetings. In parallel, rules for data sharing and joint publication were developed by a group especially assigned for this task. The finished Partnering Declaration was signed by members at Workshop 4 in August 2014. Before this workshop, a questionnaire was sent out to project members about their perceptions of how well the project performed in relation to goals. The answers reflected the delays in the project, both due to the late start of projects not funded initially and the slow process of finding a joint test site. Thus, some projects were active and more closely coupled, while others were struggling with internal issues.

Table 3: Results of group discussions on potential synergies and risks associated with research collaborations

Theme 1: General	
Opportunities	**Risks**
Higher creativity and cross-fertilisation of ideas	Free-riding as participants want to have benefits without contributing
Opportunities for future research collaboration	Too much time spent on meetings, communication and coordination
Better quality of problem formulation and results	Unclear division of responsibility
Individual satisfaction by opportunities for making new friends, expanding professional networks and having a good time	Relationships to relevant partners outside the network suffer
Arranging joint PhD courses, organization of summer schools, presentations tours, etc.	Ideas developed in the project are used in applications or publications with other partners in an unfair way
Theme 2: Data sharing and quality	
Opportunities	**Risks**
More and better results for the same money by collaboration in data collection and sharing of data.	Opportunities for data use are lost due to insufficient communication between projects.
Discover new uses of results for other projects and purposes.	Different groups and individuals have different quality standards and requirements; some may have to do additional work to benefit others.
Better quality of data and improved methods by collaboration and peer review.	Results and data are published without consent and coordination.
	Mismatched time schedules
Theme 3: Publication and impact on the research field	
Opportunities	**Risks**
More and higher quality publication by collaboration and peer review	Contributions are not acknowledged by co-authorship
More co-publication	Results and data are published without consent and coordination
More citations – higher h-index	Unintended plagiarism due to lack of communication
Theme 4: Impact on society	
Opportunities (no risks were identified)	
More and better results/tools for the same money	
Improved understanding between academia and industry	
Better opportunities to get questions important to practice addressed	
Influence design standards (norms)	

In parallel, user value issues were explored, and Workshop 3 in February 2014 was organized in collaboration with industry. Here, user values of each project were discussed in smaller groups. The time was however short and the industry participants less informed about the research projects. Thus, the discussions served more to increase the awareness of implementation aspects than to produce sharp results.

Collaboration experiences

There were varying perceptions about the collaboration between the TRUST projects. The general view was that it had been positive in building relations between researchers:

> "TRUST has been good in that all the major universities have been involved and have been able to meet. Also, the research projects have transcended some disciplinary boundaries between soil and rock specialists, who do not get that many chances to meet."

Many new relationships and some new collaborations have been developed, resulting in research application involving research environments that previously had no contact. For example, the research team from project 2.2 was invited to participate in a pilot project run by the GeoBIM team (project 4.1) at Tyréns. Also, project 3.3 collaborated with project 2.2 in a project to detect penetration distance of grouted cracks. In particular, the PhD students have expanded their networks, which was mentioned by many participants as valuable for the future. Reference was often made to a previous large collaborative project that had been successful in establishing contacts between PhD students at various universities (Väg, bro, tunnel).

Regarding the ambitions to make use of the platform to promote innovation and change in the industry, the view was that especially the younger researchers had become more aware of how their results would be implemented in practice and the general drivers and obstacles to implementation. The ambitions to jointly influence practice had however been only partly fulfilled, although individual projects had been successful in this respect. The perceived causes were delays in combination with a lack of resources both for management and for participating in TRUST activities.

As already mentioned, it was not evident for BeFo to fund the management project, since it was not a conventional technical research project, and the decision to fund it referred to the part investigating and analysing the innovation processes (this report). The funding applied for the management project was not based on assessments of actual needs but on the amount that the TRUST management team believed to be possible to get funding for. Thus, this part was insufficiently funded from the start. When the intended joint test site did not work out as previewed, it became the responsibility of the management team to find a new site. These problems added a lot to this task, and the two members from Tyréns put in significant additional time to support the university project manager.

Another problem was that the research projects had applied for funding individually and since no one could be sure that the TRUST management project would receive funding, the research projects had not included time for participating in TRUST activities in their applications. Thus, some members felt that they could not put in the time necessary to really contribute in TRUST although they would have wanted to. Also, all projects had their own reference groups to manage, and the TRUST collaboration became an additional communication and administration activity on top of the regular activities.

This quote from a consultant summarises the views of many participants:

> "There is no real support for collaboration within TRUST. Collaboration is desired. But it is not actively promoted and there are no incentives. This implies that the researchers pursue their own interests, which is logical since they are required to publish their results. It's easy to say that we will collaborate but when there are no resources it will not happen. But this is isn't something that I thought about initially, then I looked forward to collaborate with all these bright people." (Consultant)

8 DISCUSSION

8.1 Strategies and processes

First, it should be noted that underground construction is an area where comparatively much research is carried out and university-industry collaboration is lively. Still, our results confirm many of the findings in previous research on innovation in construction (summarised in Ch. 1.2 in this report): the small resources within companies devoted to research and innovation, the importance of champions at the project level and the difficulties to disseminate knowledge between projects. The study shows that establishing and maintaining a long-term organizational strategy in a project-based procurement regime is not easy. Interviewees reported that new knowledge is sought for and implemented when there is a problem in a construction project that cannot be solved with conventional technology, but that wider dissemination of these new practices is conditional on a number of factors that are hard to control. Especially the interviews with the contractors illustrate how sensitive their innovation processes are to chance factors such as timing of new relevant business projects and the experiences and knowledge of the individuals that happen to be assigned to a specific project. Contractors do not know which projects will come up for tendering and which tender competitions they will win. In this respect, a client is more in control. However, the interviewed client representatives express similar difficulties as the contractors do in driving innovation more strategically on the organizational level. Thus, the knowledge gained is easily lost.

There are organizational level R&D strategies, but the connection to the development work that is actually carried out within technically defined domains such as rock engineering is weak. In the STA there are general strategies formulated at both the political and top management levels, but these do not seem to be important for steering this kind of research or its implementation. The same appears to be true for companies: for collaborative research involving universities, top level strategies are often related to participation in flagship projects on the national or EU-level. Actual strategies for driving and disseminating more traditional disciplinary research are informal and developed by individual specialists, who use their personal contacts to negotiate access to construction projects for testing and marketing new methods within their organizations.

The interview results also confirm previous observations (Perkmann and Walsh, 2007) that there are many drivers for firms to engage in R&D collaborations, and that especially for projects with public funding implementation of results is not a primary motivation. Interviewees emphasised that R&D collaboration provided access to knowledge networks, for example by enabling participation in reference groups and communities such as BeFo. Another key goal was to support M Sc and PhD education for future recruitment. Thus, the individuals themselves were often the most significant output, not their research results. To attract and keep these highly skilled individuals, their employers had to give them the opportunity to continue doing research and keep contact with academia, which drives further investment in R&D. Branding, in order to market the company towards employees and customers, was an important function of R&D collaborations. For R&D that companies could benefit by gaining competitive advantage, the investment logic was different.

8.2 Changes over time in strategy and innovation capability

The last few years a more strategic approach to R&D had started to emerge in several of the participating organizations, putting more emphasis on implementation. STA had been required by government to fund primarily applied research for their own use and had started to measure impact of R&D projects. In the contractor and consultancy companies as well, there was a trend towards centralisation, where top management wished to have more influence on investments made in R&D. Examples of new organizational measures were formal application processes, internal R&D boards and innovation fairs. Inspiration grants and suggestion systems had been used before but received renewed attention. New information technology also brought about new communication channels such as intranets, web seminars and monitors in common areas.

One consultancy company was especially active in developing R&D as the basis for a partly new business model. Their goal was to use their internal research funds to develop premium services and avoid competition with low cost countries, and this meant that implementation and dissemination played a much more important role than before. Thus, globalisation acted as a driver for this company to shift their focus more towards implementation of results.

Another change was that the number of PhDs in industry had increased significantly over the last 15 years. Since these individuals tended to replace an older generation with a much lower education level, this meant that the competence level raised substantially. In two technical fields within TRUST, a combination of new research results and personnel with a PhD education had enabled a rapid increase in the adoption of new technology. This clearly illustrates that the relevance of research may be highly dependent on the capacity and resources on the recipient side. Thus, when assessing the potential value of research to practice, long term capacity building processes in industry have to be considered. To measure impact of R&D projects based on short cost savings in single projects, the way STA does today, risks to prematurely discontinue research that may be of high practical value but where the problem lies primarily on the receiver side.

8.3 Collaborative research and networks

A large number of professional networks were mentioned in the interviews, some of them more general and other more specialised. Important informal networks developed over time between PhDs and their former university departments. Apart for providing a basis for applying for funding, where the former PhD students could provide in kind co-funding and negotiate access to business projects, PhDs could also go between academia and industry to perform research, supervision and teaching, thereby increasing flexibility for small research departments. Many of the interviewed university academics had been employed by industry in periods.

This is because much of the research money in rock engineering is channelled through the funding bodies BeFo and SBUF. The STA and the companies thus delegate parts of their R&D strategy development to the networks of specialists involved in these organizations. This ensures that research projects meet scientific and relevance criteria, but these groups have small influence on implementation. There is no tradition to fund management, implementation and marketing activities other than the standard reports, articles and seminars. Further, BeFo is mainly reactive in its decision making: researchers apply for funding and the BeFo programme board approves or rejects these proposals. Thus, despite that these specialists and networks were important knowledge and innovation brokers with high impact on the industry level strategy for collaborative research, these functions were not be systematically managed. However, for open research with wider societal benefit, there should be a value in connecting specialist networks such as BeFo to higher level general and R&D management in the organizations that the specialists represent.

There is clearly much value in these networks, but there could also be cause for some caution. There is an optimal level of proximity in networks: too close is as detrimental as too distant, and innovative networks need to provide new contacts (Fitjar et al., 2016)). This became clear in the TRUST project: the most innovative collaborations were with a group which was new to most researchers in the community. Another risk with close peer networks composed of university-based academics and specialists with a research background in industry is that the need to allow for less applied research and take risks could justify a lack of focus on the difficult and messy implementation processes. BeFo, for example, acknowledges that this might be a dilemma ("We are perhaps too nice").

8.4 Lessons from TRUST

By its size, the TRUST collaboration exposed system level weaknesses that are not visible in a single R&D project. When establishing TRUST, the assumption was that a large coordinated R&D project would be better for communicating with industry and implementing results than several smaller projects.

However, it turned out to be the other way around. The existing system could handle innovation and developments in individual projects, but on the organizational level. This became evident when trying to find a joint test site for all TRUST projects. In smaller research projects, access to business projects is provided by individuals with an R&D background and personal contacts in the construction projects. Access often requires that site work is going well and that site measurements are found not to cause too much disturbance. Large programs for site measurements involving numerous actors, such as TRUST, call for planning and upfront commitment on a strategic level. This requires that central units for both R&D and operations are involved, in addition to construction project management functions. However, central R&D units by themselves have no authority to commit business project resources.

The experiences from TRUST showed that there was no system on the receiver side – and here the STA was the primary actor – that could enable a transition from the traditional bottom up, ad-hoc, individual based R&D regime to an organizational strategy based on a national level problem identification. The scenario analysis that led up to the initiation of the GeoInfra call was not reflected in any official innovation strategy of the STA. Thus, TRUST and STA seemed like a perfect match due to their national coverage, but in practice the size of the project turned out to be a major disadvantage. Moreover, despite that several STA people with extensive practical experience were involved, no one saw these problems coming when planning for the joint site in the early phases of TRUST. This suggests that important aspects and shortcomings of the innovation system are poorly understood not only by researchers but also by the key decision-makers in industry. This should make it difficult for them to envisage relevant and effective strategies and also to design system level developments. Another important observation was that the key position and resources of the STA created expectations among other and less central parties, and when the STA did not meet up with relevant actions there was confusion regarding roles and responsibilities both for finding a test site and for implementing research results in practice.

9 CONCLUSIONS AND RECOMMENDATIONS

This study focuses on innovation processes and implementation of research-based knowledge in relation to a large research collaboration in Swedish rock engineering, the TRUST project. The study uses an innovation system approach and considers actor/organizations (clients, suppliers and academic partners), networks and institutional aspects. According to innovation research, internal structures and competences of organizations determine their capacity to absorb new knowledge and implement research results. Such systems were still insufficient in all organizations studied, although focus on implementation and strategic aspects of R&D was increasing in several of them. Drivers for industry actors to engage in research were multifaceted and only partly related to implementation of results. Also, a previously conservative industry culture was perceived by interviewees to be changing, much due to a generation shift and a higher number of PhDs in industry.

Further, specialist networks within the organizations as well as on the industry level were found important both for knowledge exchange and in defining and initiating research projects. R&D strategies in the rock engineering area were primarily developed and implemented by individual specialists who could bridge between research activities and activities in the business projects in which they were involved. Typically, however, the research activities carried out had little or no relationship to existing formal R&D strategies. The large TRUST collaboration clearly exposed the gap between higher level R&D strategies and actual research activities within a technical/functional area such as rock engineering. It was also obvious that lack of implementation is a system-level problem and not primarily due to poor relevance or insufficient communication in individual research projects.

Innovation capabilities need to be strengthened within all actor organizations, but the Swedish Transport Administration is a key actor. This organization is the largest client for consultancy and contractor services, and also a main funder of research. However, without a clear long-term R&D strategy and relevant structures for support and implementation, it is difficult for the STA to drive development and benefit from research-based knowledge. The study identifies several internal relationships that need to be developed between specialist networks, central R&D functions, general top management and business projects. It is essential that the STA recognises its critical role in driving innovation, since an absence of higher-level planning and direction from such a dominant actor will hamper development in the whole industry.

Moreover, the geo area in general is much of an open innovation environment. Inter-organizational specialist networks are already important in the development of R&D strategies on the industry level, but this role could be better acknowledged and managed. This would require closer and more explicit ties between these networks and internal functions and processes within the organizations involved, especially on the client side. The study also showed that all actors – top management, technically oriented specialists and researchers – need to be more aware of how the innovation system works to be more effective in driving innovation and developing the system itself.

When the emphasis on implementation increases, organizations may choose to focus on short term impact measurements. However, the study showed that new methods and technologies may take time to mature and that their implementation is often dependent on skilled personnel on the receiver side. This means that there is a need to invest also in research that is relatively far from application and can supply the industry with PhDs. To avoid that potentially useful initiatives are prematurely cut back it is important to adapt evaluation processes and output measurement systems to where in the innovation process a research project is positioned, as well as the need to build capabilities on the receiver side.

Finally, it could be argued that the STA has a wide area of responsibility and may give financial support to more research activities than the organization is able to act strategically upon. However, if there is one area that an infrastructure client should prioritise it is underground construction, since the client most often is responsible for ground risk and therefore must sustain internal resources and high-level capabilities in this field.

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APPENDIX 1 Interviews

The study is based on 23 interviews with participants in the TRUST-project and other actors in the field (Table 1). The interviews were semi-structured and lasted between 1 and 3 hours. All were recorded and either transcribed or listened to and summarized, except one where notes were taken, and a summary sent back to the interviewee for checking. Further, the authors participated at the two-day workshops that took place twice a year, of which some partly dealt with implementation issues and where research planning took place.

Table 1: Interviewees: organizations and TRUST participation

Organization	Interviews
Contractor 1 NCC	R&D manager Specialists (3, 1 in TRUST)
Contractor 2 Skanska	Director of R&D (TRUST) Design manager (TRUST)
Consultant 1 Tyrens	Innovation manager (TRUST) Business developer Geo (TRUST)
Consultant 2	Technical manager (TRUST)
Client STA	Technical manager (TRUST) R&D project sponsor Specialist division manager Technical manager Geo (TRUST) Project manager
Lund university (2) Chalmers University of Technology KTH Royal Institute of Technology Luleå University of Technology Uppsala University	TRUST Research project managers, all Professors or Associate Professors
Others	Individual consultant Geo area Large public client (TRUST) BeFo representative (TRUST)

Altogether, the interviews constitute the basis for four themes, covering different dimensions of the sectoral innovation system. These are:

Theme	Interviewees
General views on drivers, obstacles, institutions, actors, and networks shaping R&D collaboration and innovation	All interviewees
The innovation capabilities of firms/organizations in the industry	Interviewees at the Swedish Transport Administration, contractor companies and engineering consultancy firms
Initiation and implementation processes related to the TRUST research projects.	Primarily academic TRUST project leaders, but also industry representatives
The TRUST collaboration process	Interviewees participating in TRUST.

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