From ideas to construction innovations: firms and universities collaborating

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Abstract

The purpose here is to study patterns of project collaboration found in one government supported programme for construction innovation. Preferred types of interaction were identified using data from two questionnaire surveys, one with experienced construction sector respondents and one aimed at construction researchers. All sixteen development projects within the Swedish Bygginnovationen programme were investigated, relying on documents and a survey of project managers. Important types of interaction, according to construction respondents, are informal contacts, joint research projects and staff mobility. For university respondents, informal contacts is also seen as the most important type of interaction, followed by MSc thesis work in firms and industrial PhD candidates. Grant applicants from manufacturing depended more on university laboratories and were less sensitive to firm/university distance. Laboratory use was also more frequent for projects relying on the field of materials engineering. In conclusion, there is a consensus about which types of collaboration are valuable. The broadness of participation in the programme, ranging over many industries, both as to origin of ideas and ultimate applications, reaches beyond narrow interpretations of the construction industry. Policy makers should recognize the innovation importance of university laboratory facilities and field testing, rather than seeing researchers as sources of ideas.

Keywords: The construction industry, innovation, universities, collaboration, Sweden.

Paper type: Research article

Introduction

Among government policy makers, belief in the importance of university-industry interaction has been strengthened over the years. In many countries, public policies for supporting university research have shifted increasingly towards promoting innovation. One reason for this shift has been a concern with perceived failures of commercializing research findings, although the available statistics can be interpreted in different ways (Jacobsson, Lindholm-Dahlstrand and Elg, 2013). As can be seen from overviews by Perkmann et al. (2013) and Bozeman, Fay and Slade (2013), the literature on university-industry relations in research and commercialization is dominated by studies of industries where patents are essential for commercial success. That interaction studies tend to gravitate towards quantitative analysis where there are ample databases in the public domain is perhaps easy to understand. Nevertheless, taking a broader view of industries and disciplines, "the thrust of their collaborative experiences is devoted to tacit knowledge rather than to intellectual property rights", according to the large Spanish survey

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reported by Ramos-Vielba and Fernández-Esquinas (2012), and this is not contradicted by other broad surveys or case studies such as that of the Chalmers Energy Initiative (Jacobsson, Vico and Hellsmark, 2014).

While a considerable and growing number of researchers have accumulated much information on types of industry-university interaction and their consequences for innovation processes (Ankrah and Al-Tabbaa, 2015), there are only few who have included the construction sector explicitly and even fewer who have dealt exclusively with this sector. Earlier researchers studying construction innovation have not dealt with government programmes that are intended to encourage commercialization of results while safeguarding the intellectual property of participating firms. In the construction industry domain, patents however appear to be of little commercial importance, and do not constitute the typical focus of industry-university collaboration (Bröchner, 2013).

An opportunity to analyse how construction research is related to the commercialization phase of innovation processes is offered by recent experiences from the sixteen development projects funded through the Swedish Bygginnovationen Programme since 2012. This construction oriented innovation programme began operating in 2011, based on an agreement between Vinnova, the Governmental Agency for Innovation Systems, and a consortium of firms in the built environment industry. Also in 2012, separate but basically similar surveys were made of opinions held by industry experts, mostly managers, and university researchers, not restricted to those involved in the programme, making it possible to analyse and compare their interaction preferences. There is the possibility that university attitudes remain coloured by the earlier government policy emphasis on dissemination of (unprotected) findings to industry (Bragesjö, Elzinga and Kasperowski, 2012) and that this presents a barrier to closer interaction in commercialization projects.

Therefore, the purpose of the present investigation is to study patterns of project collaboration and their determinants, as found in one government supported programme for construction innovation.

This paper is structured so that the literature review is followed by a more detailed description of the Bygginnovationen Programme. After having presented the methods used for data collection and data analysis, the findings from the initial attitude surveys, followed by the in-depth study of the development projects, are given. What has been found is discussed, and finally, policy conclusions are drawn.

The construction industry and university collaboration

According to an Austrian survey across scientific disciplines and industries, and compared to the engineering discipline, researchers in construction technology tended to rely more on contract research and less on personal mobility between universities and industry (Schartinger, Rammer, Fischer and Fröhlich, 2002). On the other hand, the Austrian survey revealed that the construction industry interacted with universities in a pattern resembling that for business services, although construction was much more dependent on joint research; still, when comparing manufacturers of motor vehicles with construction, construction was less engaged in joint research projects. That the choice of university-industry knowledge transfer channels varies with industry sectors and even more according to disciplines is confirmed by the quantitative analysis reported by Bekkers and Freitas (2008).

It is possible to distinguish between orientation-related and transaction-related barriers to university interaction for SMEs and large firms; Bruneel, d'Este and Salter (2010) found that the utilities and construction sector experienced higher orientation barriers than chemical-related firms, while the sector reported fewer transaction-related barriers. Examples of orientation barriers are university emphasis on pure science and lower sense of urgency among researchers. Transaction barriers include the functioning of industry liaison offices as well as rules and regulations for universities and government funding. Among the conclusions reached, collaboration experience and breadth of interactions were highlighted as lowering barriers related to conflicts of interest, although barriers related to intellectual property were a different matter.

Moreover, construction oriented research interaction in the discipline of Civil Engineering emerged with a clear profile when D'Este and Perkmann (2011) analysed data from UK investigators in the physical and engineering sciences. Why did researchers choose to interact with particular industries? Civil engineering had the highest value of ten disciplines on 'Information on industry problem' as an interaction incentive for researchers, and furthermore 'Access to materials' and 'Becoming part of a network' were important as incentives. Unlike interaction modes such as contract research, consulting, spin-offs and patents, joint research was statistically significant for Civil engineering.

Recently, the construction sector has been compared to other sectors in a study of interaction and innovation in Norwegian city regions (Fitjar and Rodríguez-Pose, 2015). Contrasting with earlier studies that have found traditional exchanges with clients and suppliers to be more important for construction sector innovation, they found that "even low-skilled construction firms seem to benefit from interaction with universities".

There are a number of studies which concentrate on particular types of interaction mechanisms, but little that is construction specific. In general, it has been found that industrial PhD candidates perform more than one function on the university-industry interface (Thune, 2009). Studying Swedish PhD candidates, Bienkowska and Klofsten (2012) analysed their attitudes to commercialization of research results, finding for the category of science and engineering that only a small minority had moved between university and a firm during their PhD education, whereas less than a third had no experience of external collaboration during the same period. Regardless of size of firms engaging in industry PhD schemes, Thune and Børing (2015) found that development of broader competencies, knowledge in key technological areas, R&D competencies and innovation capability were key results in such firms.

It is reasonable to believe that geographical proximity between firms and university researchers supports interaction. Bishop, D'Este and Neely (2011) distinguished between firms' explorative and exploitative learning, and in their study of EPSRC grant recipients, firms belonging to Utilities & Construction were more likely than firms in other sectors to see 'problem solving' as an important benefit of collaborating with universities. They also found that short physical distances were associated with 'problem solving' collaboration. The general relationship between distance and collaboration appears to be a complex matter and not just a linear relationship (D'Este and Iammarino, 2010).

The effect of firm size has been discussed by several authors. Repeatedly, earlier research has shown that firm size is linked to specific patterns of innovation. Technological collaboration is known to contribute to the innovativeness of manufacturing SMEs (Nieto and Santamaría, 2010). Both vertical partnerships and, somewhat less, collaboration with research organizations were found to be associated with product innovations. Forsman's (2011) study of innovation in Finnish small enterprises, within manufacturing and services, indicated that differences within the service sector, as well as among manufacturers, were greater than the overall differences between services and manufacturing SMEs. As usual, there are few studies with a focus on construction, but Manley (2008a) has described six Australian case studies of innovating small construction firms, finding that the more technical and unique an innovation was, the more likely the firm was to have a relation with a research centre.

Technical innovations in the US construction industry are often initiated within the construction firm, according to the survey carried out by Gambatese and Hallowell (2011). Universities can be seen as technical support providers to manufacturers looking for implementation of their innovations in construction projects (Manley, 2008b), as brought out in several case studies of R&D ties with universities; this was believed to have accelerated technology diffusion greatly. In his study of a number of Finnish construction oriented innovations, Koukkari (2014) found that the principal driver for interaction between building product manufacturers and research organizations was the need to know how a novel product would perform in its intended use.

In many countries, government policies and programmes supporting innovation in SMEs have been developed and extended (Ezell and Atkinson, 2011). These measures include support of technology transfer, diffusion and commercialization, and they may also comprise R&D performed in partnership with SMEs, access to laboratories and more broadly engage SMEs in collaborative R&D, sometimes in technology specific consortia. There are several funding mechanisms: direct R&D grants, innovation vouchers and financial support of pre-competitive research programmes. Innovative SMEs engage in both exploration and exploitation, which is particularly important for government policies to acknowledge when the commercialization phase is in focus (van Hemert, Nijkamp and Masurel, 2013). Among commercialization sources, they warn in their study of recipients of Dutch innovation vouchers against overlooking the role of advisors to SME firms.

The conceptual model underlying the present investigation is that firms and universities chose types of collaboration depending on a number of incentives or motivations, characteristics of the industries involved and also of the fields of science and technology. For particular innovation projects, it is probable that earlier collaborative experiences, advisory services, government project funding and geographical proximity support collaboration and influence the choice of type of collaboration.

The Bygginnovationen programme case

How the Swedish Bygginnovationen programme has been organized can be understood against the evolution of government R&D policies, where the scientific quality of projects oriented towards applied research within specific sectors, including construction, came under scrutiny in the 1990s. Major policy change across disciplines and sectors took place in 2000. Ensuring that research met higher standards of scientific quality might however reduce its potential for commercialization, and consequently, stronger support measures for innovation were introduced (Brundenius, Göransson and Ågren, 2011). The concept of innovation systems acted as a guideline, and the creation of clusters and networks was now emphasized. To take only one example of basic changes in the profile of government innovation policies, Levén, Holmström and Mathiassen (2014) have analysed the management of the network in a Swedish cross-industry programme, ProcessIT Innovations, with financial support from Vinnova.

Earlier Swedish policies for both government and joint private sector support of construction R&D included that project results should always be in the public domain. Obviously, this principle reduces appropriability of results and lowers incentives for firms to engage in supported research, if they are close to commercial introduction. During the first half of the 1990s, the Swedish Council for Building Research entered into framework agreements with industry associations for private sector cofinancing of projects receiving government grants. Although this may have contributed to a higher degree of construction sector relevance of university research, the sweeping change in government research policies in 2000 led to the inclusion of built environment research funding in a new research council, Formas, with a clearer scientific profile (Bröchner and Sjöström, 2003). At the end of the decade, industry concern with the ability to link university research to construction innovations led to discussions with Vinnova, the Governmental Agency for Innovation Systems. Vinnova has the task of promoting sustainable growth by financing R & D and developing effective innovation systems. The outcome of these discussions was the Bygginnovationen programme.

The programme, which started operating in 2011 (Kadefors and Bröchner, 2014), was based on an agreement between Vinnova and a consortium of currently 22 firms in the built environment industry, including at least one each of general and specialist contractors, engineering consultants, architects, materials suppliers and property developers. In itself, the consortium formation recognized the need for a network approach, which prior government policies for construction R&D lacked (Ingemansson Havenvid, 2015).

The total programme budget for 2011-2015 has been SEK 90 million (about EUR 10 million), half from Vinnova and half from the Swedish industry. The co-financing from the consortium firms is primarily in-kind through work efforts by their employees. Three types of grants have been offered to firms, which need not be (and often are not) members of the consortium: innovation vouchers, planning grants and development grants. No new development grants have been awarded since 2014.

The overall purpose of the programme was stated as to develop a strong and lasting innovation environment for Swedish construction; bridging the academia/industry gap and promoting the commercialisation of knowledge, solutions and research results. Prioritized areas were indicated as information and communication technologies, efficient processes as well as sustainable growth. Programme activities were expected to produce (i) short-term results such as new collaborative relations, more demand-driven research, new solutions/prototypes/software, new commercial contacts, and increased knowledge and competence in firms; and (ii) medium-term results including new products, processes and services developed by the firms, reducing costs, raising productivity and contributing to increased sustainability, increased demand for research graduates within firms, and attractive research environments within universities and industry. The overall goals were said to be green growth that generates increased employment and turnover, stronger competitiveness of Swedish construction and closing the gap between industry and the university and research institute sector.

One feature of the programme is a business advisory committee, a group of 40-odd industry specialists with considerable practical experience of developing products, technologies and processes in the industry. Each application is assessed by at least three members of this committee before the programme board recommends a grant decision to Vinnova. In many cases, the assessment includes an element of advice intended to be of value to the applicant, even if the application happens to be rejected. Applications can be submitted as late as 15 workdays before board meetings, which implies that a rapid process is emphasized. All involved in the processing of applications are bound by confidentiality agreements regarding the information provided by applicants. The programme is intended to preserve secrecy of project details and thus increase commercial appropriability of results.

As of September 2015, 118 grants had been awarded. Of these, 64 grants engaged universities and 105 grants SMEs. There had been 75 applications for innovation vouchers (leading to 33 awarded grants), 141 applications for planning grants (64 awards) and 63 applications for development grants (16 awards). Grants for development projects were typically in the range of 1-2 million SEK, matched by required internal funding by the applicant firm. In many cases, applications for a development grant were preceded by either vouchers or planning grants or by both, which means that the total number of innovation ideas was lower than that of grants awarded. Of all 16 awarded development grants, eight explicitly included university funding, and collaboration was required for all development projects. Table 1 gives an overview of the projects, also including their relation the prioritized areas in the programme. Since ICT and efficient processes were found to be overlapping, only ICT is included in the table; sustainable growth, the third area, is represented by Energy, although there were elements of environmental sustainability in almost all projects.

Table 1: The sixteen Bygginnovationen development projects; funding and profiles

Project technology	University funding	ICT	Energy
Shotcrete simulator	x	x	
Ground storage cooling and heating system	x	x	x
Road marking robot		x	
Construction resource planning system	x	x	
Gypsum wall system			
3D woven construction beams	x		
Fibre transmitted solar lighting			(x)
Roof solar collector			x
Wireless sensors in concrete	x	x	
Rock grouting visualization system		x	
Train type vertical transportation in tall buildings			
Quality control system for self-compacting concrete	x		
Early stage concrete cracking prevention	x		
Wooden tower for wind turbines	x		(x)
Automatic tiling system for large floors		x	
Single-family house configurator system		x	

Research method

It has not been obvious how university researchers would be affected by the creation of Bygginnovationen, a programme directed towards commercialization. This issue can be approached as an example of dynamics in industry-university collaboration.

From the literature review above, and in particular from the overview provided by Perkmann et al. (2013), fifteen types of industry/university interaction were identified. First, there are informal contacts between researchers and industry employees; this may stand in a relation to part-time employees, of which industrial PhD students are a subset. There may also be staff mobility in one or both directions between firms and universities. Research projects can be joint research projects, where firms and universities work jointly, or there can be contract research, where industry emphasis is on results rather than interaction during the research process itself. Consultancy, where university researchers provide advice on a fee basis, is another related type of interaction. Firms and universities may invest in common laboratories and run them on a joint basis. As universities have twin functions of research and higher education, a broader understanding of the setting where research interaction takes place will also include student internships with firms, MSc thesis work in firms (BSc theses are of less importance in the Swedish context where many civil engineering students go directly to the MSc level) and recruitment of graduates. Furthermore, there is industry participation in continued education courses and industry reading scientific publications, which is usually understood today as primarily referring to peer-reviewed articles. Finally, one specific type of interaction is university start-up firms.

Many studies of university-industry knowledge transfer have studied interaction from only one side of the relationship, but Ankrah, Burgess, Grimshaw and Shaw (2013) have investigated both groups within five UK case studies of research partnerships, finding that there is little difference in motives. This must be interpreted with care, since it is probable that partners in partnerships can be thought to hold more similar opinions of collaboration.

There are several empirical sources of data. First, data were collected in 2012 through a short questionnaire five-degree Likert scales, used at a workshop with construction experts from industry, giving 17 responses; furthermore the same questionnaire received 24 responses from other experts contacted for the development of a national innovation strategy for the built environment industry. These industry respondents are intended to be representative of managers with long experience of construction innovation and of contacts with researchers.

In the same year, the collaborative organization of the Swedish Universities of the Built Environment held a national meeting for research group managers. A corresponding collaboration questionnaire received responses from 29 university researchers on that occasion. These 29 respondents are a sample of the construction oriented researchers in the four Swedish universities (Chalmers University of Technology, KTH Royal Institute of Technology, Luleå University of Technology and Lund University) that have course and research based MSc (C.E.) programmes. A majority of participants in the 2012 annual meeting participated in the survey. There is a source of bias in that researchers who chose not to participate in the national meeting and of those who did participate but failed to return questionnaires might be less interested in policy issues or less eager to interact with industry. Questionnaire responses have been subjected to correlation analysis.

The third set of empirical data, related to the 16 development projects in Table 1, comes from the original funding applications, advice documents from the Bygginnovationen Business Council and a series of interviews held in 2015 with managers of the supported projects. Information from company web pages has also been used in this context. Semi-structured interviews were carried out, supplemented by basic data from grant applications and industry databases. The interview questions were five and concerned in which organizational context the original innovative idea arose, the time elapsed from the original idea to the first application for a Bygginnovationen grant, the length of prior relationship between the firm and the university/ies before the first Bygginnovationen grant was awarded for the idea, which the important milestones were in the process from the first idea to the first grant application and which were the main functions of university participation in the project. Functions were classified according to categories in prior literature: laboratory use, field measurement, analytical understanding, problem solving, risk reduction, project management, computing power, access to previous research, access to foreign expertise, access to fundamental research, access to regulatory authorities. Ultimately, three categories of functions were added in the analysis, based on interviewee suggestions: access to industry, project management, sounding board for ideas.

Furthermore, data were collected on university funding in grants, distances between firms and universities, part-time positions, type of innovation, scientific disciplines, firm size, age of firm, project manager education, industries to which firms belonged, industries where productivity effects of the innovation could be expected.

Findings

The attitude surveys

Based on interaction types identified in earlier literature, fifteen types were included in the questionnaire. The outcome for construction sector respondents (N=41) can be seen as means, standard deviations and pairwise correlations in Table 2; corresponding data for university respondents (N=29) are in Table 3.

According to construction respondents and the mean values in Table 2, there are five important types of interaction: informal contacts, joint research projects, staff mobility, MSc thesis work in the firm and recruitment of graduates. Turning to the university respondents in Table 3, informal contacts is also seen as the most important type of interaction, followed by MSc thesis work in firms, having industrial PhD candidates, part-time positions and joint research projects. However, the differences in ranking are small. Both groups of respondents agree on assigning the lowest rank to university start-up firms; this might indicate that academic spin-offs are felt to lie outside the mainstream of university-industry interaction, and the background of survey participants as established industry experts and experienced university researchers could also be reflected in their views.

Essentially, university prioritization of the fifteen ways of interaction agreed with the opinions of those interviewed in the firms, although staff mobility and university consultancy appear to be more popular with firms than with university researchers. On the other hand, thesis work in firms and industrial PhD candidates received higher values for universities than for firms.

Table 2**:** Construction sector views of types of interaction between firms and universities: descriptive statistics and correlations

Type of interaction	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Informal contacts	3.02	0.85														
2 Staff mobility	2.90	1.02	0.61													
3 Part-time positions	2.78	1.06	0.53	0.79												
4 Industrial PhD candidates	2.71	1.05	0.45	0.58	0.75											
5 Joint research projects	2.95	0.95	0.47	0.56	0.66	0.56										
6 Common laboratories	2.34	0.94	0.40	0.48	0.50	0.46	0.55									
7 MSc Thesis work in the firm	2.88	0.98	0.54	0.46	0.46	0.38	0.32	0.26								
8 Recruitment of graduates	2.88	1.05	0.42	0.34	0.40	0.37	0.50	0.37	0.62							
9 Student internships	2.85	1.06	0.34	0.36	0.46	0.39	0.54	0.40	0.68	0.77						
10 Contract research	2.02	0.94	0.35	0.42	0.26	0.34	0.37	0.28	0.22	0.31	0.21					
11 Consultancy	2.39	0.80	0.46	0.60	0.43	0.38	0.52	0.42	0.29	0.09	0.25	0.42				
12 Participation in conferences	2.44	0.81	0.42	0.57	0.50	0.51	0.68	0.49	0.32	0.30	0.34	0.25	0.58			
13 Continued education courses	2.44	0.87	0.29	0.50	0.43	0.23	0.51	0.40	0.39	0.47	0.51	0.42	0.43	0.47		
14 Scientific publications	2.00	0.81	0.26	0.46	0.44	0.41	0.49	0.63	0.32	0.35	0.41	0.13	0.46	0.69	0.43	
15 University start-ups	1.95	0.89	0.36	0.41	0.41	0.25	0.29	0.44	0.39	0.42	0.44	0.24	0.41	0.24	0.48	0.45

N = 41. Scale: 0-4. S.D. = standard deviation

Table 3: University views of types of interaction between firms and universities: descriptive statistics and correlations

Type of interaction	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Informal contacts	3.28	0.65														
2 Staff mobility	2.34	0.86	0.21													
3 Part-time positions	2.93	1.07	-0.28	0.22												
4 Industrial PhD candidates	3.10	0.94	-0.05	0.35	0.40											
5 Joint research projects	2.90	0.98	0.16	0.17	0.06	0.17										
6 Common laboratories	1.90	1.35	0.12	0.16	0.39	0.29	-0.06									
7 MSc Thesis work in the firm	3.24	0.74	0.30	0.20	-0.21	0.01	0.18	0.17								
8 Recruitment of graduates	3.07	0.84	0.23	0.36	-0.11	0.17	-0.08	0.20	0.43							
9 Student internships	2.45	1.02	0.35	0.39	0.04	0.06	0.12	0.14	0.47	0.67						
10 Contract research	1.97	1.09	0.07	0.09	-0.10	0.00	0.33	0.22	0.37	0.20	0.40					
11 Consultancy	1.69	1.00	-0.08	0.21	0.18	0.19	-0.07	0.50	0.11	0.36	0.42	0.55				
12 Participation in conferences	2.10	0.98	0.52	0.26	0.18	0.22	0.01	0.39	0.16	0.25	0.38	0.07	0.25			
13 Continued education courses	2.03	0.98	0.04	0.50	0.28	0.19	0.19	0.08	-0.16	-0.09	0.13	0.34	0.19	0.00		
14 Scientific publications	2.07	0.92	0.38	0.29	0.15	0.40	-0.11	0.32	0.18	0.36	0.27	0.00	0.22	0.67	-0.04	
15 University start-ups	1.41	0.78	0.19	0.37	0.25	-0.01	0.15	0.25	0.32	0.23	0.39	0.61	0.31	0.22	0.54	0.01

N = 29. Scale: 0-4. S.D. = standard deviation

It is obvious that informal contacts, joint research projects and part-time positions were ranked highly by both industry and academia. The correlation matrices reveal that industry views on joint research projects are correlated with their views on a number of other types of interaction (conference participation, part-time employment and internships), but for university respondents, views on joint research, however favourable, are less correlated with those for other types of interaction. There is no immediate explanation for this discrepancy between industry and university views, and it is possible that a closer investigation of the development projects supported under the Bygginnovationen programme will offer clues.

Analysis of the development projects

The variety of technologies supported by the Bygginnovationen development grants has already been shown in Table 1. Eight of the sixteen projects depended strongly on information technology, either as employing robotics or as essentially dealing with innovative software solutions. Many projects appear to have been driven by concerns with environmental sustainability, although energy projects formed a minority. Four projects aimed at concrete structure applications. University funding was explicitly covered within the development grant for eight of the projects.

An analysis of all advice messages from the Business Council to ultimately successful recipients of development grants shows that usually, the advice given concerns detailing of commercialization plans and business models. Occasionally, technical issues such as conformity with fire and noise regulations were brought up by the Business Council advisors. There are examples of advice given to the effect that applicants for development grants should seek collaboration with relevant university researchers: "Show ties to earlier and ongoing research", "Clarify whether researcher competences are in the team", "Indicate how the project organization is tied to relevant academic research", "Weak attachment to the world of research", "There should be collaboration with the research world". Thus there was an active encouragement of stronger links between firms and researchers in the case of a few projects where this appeared to be necessary.

There were no signs of individual mobility in either direction, university-firm or firm-university, within the duration of these projects. However, part-time employment in industry and university is present in several projects, and also that employees in firms make use of what they have been involved in earlier as university students or researchers themselves.

Table 4: Projects (N=16) according to applicant firm industry (NACE Rev. 2)

Industry	Applicant firms (N)	Projects relying on laboratory use	Distance firm-university [mean, kms]	Years from idea to grant application [mean]	Project manager education	Functions of university participation
C Manufacturing	6	4	491	3.9	BSc, MSc (3), PhD (2)	analytical understanding (4), project management (2), computing power, problem solving
F Construction	1	0	1027	5.5	MSc	analytical understanding, field measurement
J Information and communication	1	0	5	5.5	MSc	-
L Real estate activities	1	1	397	4.0	MSc	analytical understanding, field measurement
M Professional […] activities	6	2	21	4.8	MSc (6)	field measurement (3), sounding board (2), access previous research, access to industry, analytical understanding, problem solving, risk reduction
N Administrative and support service activities	1	0	95	4.0	MSc	analytical understanding, sounding board

The NACE (Rev. 2) two-digit code for industries can be used as a rough measure of where a firm is on a manufacturing – services axis. The pattern as seen in Table 4 is different for the applicant firm and (Table 5) the industry/ies where productivity effects (Bröchner and Olofsson, 2011) are expected to arise. Although the Bygginnovationen programme is intended to support construction innovations, almost all applicant firms are classified under other industries (Table 4), primarily as manufacturers or service firms. Table 5 gives a different picture where construction dominates as the target industry where productivity effects of the innovation projects are likely to arise. Since the internal resources for managing innovation projects might be insufficient among construction contractors, it is only to be expected that applicant firms are drawn from a broader range of industries.

Projects where the applicant firm industry was in manufacturing were more associated with use of university laboratories; at the other end of the scale, applicant firms in the service sector would seldom rely on laboratories and would more often look for shorter distance university collaboration. On the other hand, as emerges from Table 5, for projects where the target industry for results was in the service sector, the time elapsing between original idea and the first grant application tended to be longer than when targeting manufacturers. The innovation process between the original idea, which in all cases except one arose within the applicant firm and not in a university setting, and the first application for any type of Bygginnovationen grant, took between one and eleven years, with an overall average of 4.4 years.

For Table 6, relevant parts of the OECD Revised Field of Science and Technology (FOS) classification in the Frascati manual (OECD, 2007) have been used. The largest group of projects depends on mechanical engineering (2.3 in Table 6), not relying on university laboratories except for one project. Mechanical engineering is associated with shorter distances between firm and collaborating university, and the gestation period for project ideas is also shorter than for other fields. Project managers with a PhD degree are found under electrical engineering (2.2) and chemical engineering (2.4); materials engineering (2.5) is a field with a lower average level of formal education among project managers.

Table 5: Projects (N=16) according to target industry (NACE Rev. 2)

Industry	Projects within target (N)	Projects relying on laboratory use	Distance firm-university [mean, kms]	Years from idea to grant application [mean]	Project manager education	Functions of university participation
C Manufacturing	2	1	662	2.8	MSc, PhD	problem solving (2), analytical understanding, project management
D Electricity […] supply	1		479	2.0	MSc	analytical understanding, field measurement
F Construction	11	4	287	4.3	BSc, MSc (9), PhD (2)	analytical understanding (4), problem solving (3), field measurement (2), project management (2), access to previous research, access to industry, risk reduction, sounding board
L Real estate activities	2	2	201	9.5	MSc (2)	analytical understanding, field measurement, sounding board
M Professional […] activities	1	1	727	7.0	PhD	project management
P Education	1	0	1027	5.5	MSc	analytical understanding, field measurement

Note: There can be more than one target industry for a given project. One project targets homeowners.

Table 6: Projects (N=16) according to fields of science and technology (OECD, 2007)

Field of science and technology	Projects relying on field	Projects relying on laboratory use	Distance firm-university [mean, kms]	Years from idea to grant application [mean]	Project manager education	Functions of university participation
2.1 Civil engineering	2	1	404	6.0	MSc (2)	field measurement (2), access previous research, access to industry, analytical understanding, risk reduction
2.2 Electrical engineering, electronic engineering, information engineering	4	1	592	3.5	MSc (3), PhD	analytical understanding (3), problem solving (3), field measurement, project management
2.3 Mechanical engineering	6	1	23	2.5	MSc (6)	analytical understanding (3), field measurement (2), sounding board (2)
2.4 Chemical engineering	1	1	727	7.0	PhD	project management
2.5 Materials engineering	4	3	240	6.4	BSc, MSc (3)	analytical understanding (2), computing power, project management, sounding board
5.1 Psychology	1	0	1027	5.5	MSc	analytical understanding, field measurement

Note: There can be more than one field for a given project.

Reasons given by firms for their university collaboration were (in descending order of frequency of mention): analytical understanding, use of laboratory, field measurement, sounding board for ideas, project management, problem solving, risk reduction, computing power, access to previous research, access to fundamental research and perhaps more of a surprise: access to industry, which here means that university researchers are understood as having deeper knowledge of the construction industry than an innovating firm in other industries would have. Field measurement is more strongly associated with university funding included in the grant received by the firm.

Moreover, when interviewed, more than one applicant spontaneously emphasized the market effect of having innovative ideas recognized by a joint industry-government programme such as Bygginnovationen. This should probably not be underestimated as a driver for grant applications.

Firms with a history of university collaboration over decades were obviously old and had more than 100 employees. The smaller firms, with employee numbers in the 0–18 range, were between 2 and 23 years old. Only three of the sixteen firms had more than 100 employees, and these had been founded three or four decades ago. The programme is thus dominated by SMEs, although a clear majority of the consortium firms bound by the fundamental programme agreement with Vinnova are large firms.

Discussion

Earlier studies have often found that construction innovation is more often process than product innovation. In the Bygginnovationen case, there has been a new emphasis on safeguarding the intellectual property of participants, and this probably lies behind the tangible product orientation of many of the development projects analysed here. There might have been a pent-up industry demand for product development of a type that fits in with recent government policies for innovation support. The broad mix of product and process innovation within the programme is also connected with the variety of firms which it has attracted outside the construction industry, as it is traditionally and narrowly defined in official statistics. It is thus necessary to recognize that productivity effects may arise in a number of industries other than construction as a consequence of construction innovation projects, just as the project initiatives may come from other industries.

Comparing results here with what other researchers have found, we find that many of the Bygginnovationen joint projects have been able to combine transfer of tacit knowledge with observing intellectual property rights, rather than opposing these two aspects (Ramos-Vielba and Fernández-Esquinas, 2012). In general, the views on interaction did not differ much between industry and university survey respondents, thus not confirming the existence of what Bruneel, D’Este and Salter (2010) saw as orientation barriers. Both industry and university respondents preferred joint research to contract research, which differs from the conclusion reached for Austria by Schartinger and her co-authors (2002), while our results agree more with the UK data presented by D’Este and Perkmann (2011).

As to the functions of university involvement in the development projects, ‘problem solving’ was a recurrent reason for firms to engage with researchers, consistent with the findings reported by Bishop, D’Este and Neely (2011). Also, the view of universities as technical support providers (Manley, 2008b) and as helpful in predicting the performance of novel products (Koukkari, 2014) was possible to recognize in the Bygginnovationen projects. Another observation that was confirmed was that the locus of innovative technical ideas often is within construction firms (Gambatese and Howell, 2011).

Our findings related to distance between firms and universities appear to conform to the observation by D'Este and Iammarino (2010) that distances that do not exclude a physical meeting in the space of a single day of travel are acceptable for specialized laboratory facilities, whereas more general involvement in problem-solving is more often sought in nearby universities.

The interaction mechanism of staff mobility ranked higher with sector respondents than among university respondents, but there were no actual cases of job changes identified among the sixteen development projects. This could partly be explained by the typical average project duration, less than two years. Part-time industry/university positions were also highly ranked (here more by university than industry respondents in the survey), and these were involved in no less than seven of the sixteen Bygginnovationen projects.

Conclusions

This investigation leads to two major conclusions. The first one is that there is a broad consensus across construction industry experts and university researchers about which types of collaboration are valuable. There are only minor differences in views here, with joint research projects ranked higher than e.g. contract research. Secondly, the broadness of participation in the programme, ranging over a number of industries, both when considering the origin of ideas and the ultimate commercial applications, reaches far beyond any narrow interpretation of the boundaries of the construction industry. Construction innovation ranges from manufacturing to the service industries, engages firms of many sizes, and its effects are also to be found in a wide range of firms. This very broadness creates a problem when predicting and evaluating the impact of programmes of the Bygginnovationen type.

An obvious limitation of the present investigation is that it has been restricted to the single case of the Swedish Bygginnovationen programme and its sixteen development projects. Many of the results are in line with what earlier researchers have found, but the emphasis on protecting the intellectual property of firms that participate does make it difficult to find basically similar programmes in other countries for comparative purposes. Given the global trend in innovation policies, there should be more opportunities in the future for international studies.

As to programme policy tools, it appears that the role of advisory functions, such as those performed by the business advisory board within Bygginnovationen, merits further analysis. In a wider perspective of government policies for higher education and university research, the importance of laboratory facilities in particular phases of many innovation projects has to be taken seriously. For construction research, and according to both industry and university respondents in the present surveys, it is university laboratories that is preferred to the alternative of common investment and operation of a laboratory. A similar case can be made for government investment in equipment and staff for performing field testing of new technologies. The long term durability of materials, components and systems are often crucial issues in construction, and also the exposure to many uncertain environmental loads on facilities in use, explain much of the importance of laboratories and field measurements.

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