Abstract: Construction engineering is a vital discipline in industry practice, providing essential facilities and systems for modern society. Despite its undisputed importance, basic research intensity and focus has been declining, which is compounded by challenges in collaboration between industry and academia. This study therefore aimed to revitalize construction engineering by emphasizing basic research, exploring barriers and enablers, and collaboratively establishing an ambitious research agenda. These objectives were addressed via a dedicated research conference and workshop, held in March 2014 in Seattle. The event outcomes included new collaborations for 49% of workshop participants. In addition, the workshop identified four fundamental attributes of basic construction engineering research, including the drive to further knowledge, to improve construction delivery, to serve industry, and to pursue sustainability. Ultimately, this paper presents a research agenda for construction engineering based on workshop participant contributions. This agenda is a call for action that focuses attention on global systems and sustainability (for example, creating and maintaining vast distributed infrastructure systems), technology and management (for example, designing for the hybrid technical-human nature of construction engineering), and research methods (for example, adapting interdisciplinary research methodologies for construction engineering research). It is intended as the starting point for junior and senior researchers, industry representatives, and government agencies to develop, participate, and support their targeted research projects that endeavor to address a specific part of one of these major themes.
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Contributions to the Body of Knowledge

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Specific contributions to the body of knowledge are the first explicit basic research agenda for construction engineering itself. It calls on academia and industry to collaboratively develop their specific research projects to address global systems and sustainability (for example, creating and maintaining vast distributed infrastructure systems), technology and management (for example, designing for the hybrid technical-human nature of construction engineering), and research methods (for example, adapting interdisciplinary research methodologies for construction engineering research). Second, it fosters an interdisciplinary view of construction engineering, by having embedded for the first time a group of non-construction researchers from backgrounds as diverse as behavioral psychology, linguistics education, urban development, and industrial engineering into the entire event. And last, not least, the detailed documentation of the conference and workshop can serve as a template for events in future decades to occasionally update the agenda and measure the accomplishments that will have been made until then.
ABSTRACT

Construction engineering is a vital discipline in industry practice, providing essential facilities and systems for modern society. Despite its undisputed importance, basic research intensity and focus has been declining, which is compounded by challenges in collaboration between industry and academia. This study therefore aimed to revitalize construction engineering by emphasizing basic research, exploring barriers and enablers, and collaboratively establishing an ambitious research agenda. These objectives were addressed via a dedicated research conference and workshop, held in March 2014 in Seattle. The event outcomes included new collaborations for 49% of workshop participants. In addition, the workshop identified four fundamental attributes of basic construction engineering research, including the drive to further knowledge, to improve construction delivery, to serve industry, and to pursue sustainability. Ultimately, this paper presents a research agenda for construction engineering based on workshop participant contributions. This agenda is a call for action that focuses attention on global systems and sustainability (for example, creating and maintaining vast distributed infrastructure systems), technology and management (for example, designing for the hybrid technical-human nature of construction engineering), and research methods (for example, adapting interdisciplinary research methodologies for construction engineering research). It is intended as the starting point for junior and senior researchers, in-
dustry representatives, and government agencies to develop, participate, and support their targeted re-
search projects that endeavor to address a specific part of one of these major themes.

Keywords: Industry; Construction Engineering; Basic Research; Research Needs; Agenda.

INTRODUCTION

The Construction Engineering Conference (CEC) was held in Seattle, Washington on March 27-29, 2014. This conference gathered construction academics and practitioners together to discuss industry needs and to create beneficial relationships. The last day of the conference was a workshop entitled Promoting Basic Construction Research that was sponsored by the National Science Foundation (NSF).

The workshop was held in order to state a research agenda for construction engineering that encompasses the knowledge and insights of a broad representation of the research community itself. Per the workshop objectives, this article presents the collective answers to the following questions:

- Where are the major basic research needs in construction engineering?
- Why is basic construction engineering research important?
- What are the barriers and enablers for performing basic construction engineering research?
- What is basic construction engineering research?

This paper analyzes and archives the collective knowledge of participants of this workshop, organized per the guiding questions above, with the goal of advancing basic research in construction engineering.

STATE OF PRACTICE

The built environment has an almost unimaginable value to society that exceeds $20 trillion; its complexity requires innovative and integrative approaches (Bordogna 1998). Construction projects are
capital-intensive and large, and frequently form part of vital infrastructure systems (Brookes 2012; Cleveland 2010). Projects have profound significance; they create essential physical facilities that preserve and improve the modern quality of life. As such the discipline merits dedicated research to advance practice.

Construction engineering has been defined as a “series of technical activities throughout the project delivery process that influence design, support construction means and methods decisions, create a safe and productive construction environment, and seek to avoid and solve the engineering issues associated with project delivery” (Federle et al. 2011, p. 717). This is complementary to construction management, which focuses on aspects such as e.g. “Managing the firm;” “Construction planning and control;” “Time scheduling;” “Cost estimating and control;” “Management of human resources;” “Project management;” “Project delivery systems;” and “Contractual issues” (Pietroforte and Stefani 2004, p. 442).

Construction engineering is a research-based discipline (Halpin 2007, p. 636 / 638) that since emerging within civil engineering has faced “skepticism regarding construction as a “research-able” area” as early as 1975. For example, according to an analysis of publication trends in the Journal of Construction Engineering and Management, construction research overall has lacked in a thorough exploration of the interfaces of social/behavioral, computing, and technological systems, and is in urgent need of more “research collaboration between industry and academia, between government and academia, and between industry and government” (Abudayyeh et al. 2004, p. 439). The research community must now “consider whether or not it wants to be a fundamental developer of theory or whether it wants to continue applying the theories of others” (Chinowsky and Diekmann 2004, p. 757). Other studies emphasized the important role of construction researchers in national policy (Handa 1996) and education (Harris 1992). Still, most publications in a premier journal emphasized construction management, not construction engineering (Pietroforte and Stefani 2004). Calls to revitalize construction engineering succinctly state its
critical needs: “Designing production systems for projects is at the leading edge of production management. Construction engineering can lead this development, extend its research agenda, and develop practitioners with capabilities long missing in the industry” (Howell et al. 2010 p. 744). Such thoughts echo those voiced much earlier (Oglesby 1982) and show the continued need for efforts intended to advance the field.

In this context a series of workshops (CMU 1999, Tommelein 1999, CII 1997, Carr and Maloney 1982, Paulson 1975) attempted to define research needs. A conference in 2010 at Virginia Tech (Federle et al. 2011) identified technical fundamentals, materials of construction, construction-applied resources, and field construction operations as core knowledge for construction engineering (Tatum 2010). Earlier meta-studies analyzed research publications (Abudayyeh et al. 2004, Pietroforte and Stefani 2004) and found increasing diversity and quality of contributions. Further issues included a “more effective implementation of new techniques, a reduction of disputes and litigation, improved contractual relationships, and professional teamwork that provides better results for the client” (Fondahl 1991, p. 380).

However, a main criticism was that “construction engineering has progressively fallen out of focus in construction project management education and research” (Howell et al. 2010, p. 740); in fact “45 years later [after a 1965 study on efficiency problems], little has changed in relation to the way work is structured – who does what, when, where, and how.” After half a century of dedicated research and education, the challenges for the next five decades are significant – rediscovering science and understanding what constitutes ‘theory’ in construction engineering, broadening its limited perspective on economic, environmental, and social aspects of sustainability, and embracing the entire life cycle of built facilities (Levitt 2007). These major ambitions are achievable if the right emphasis is set at the present time. A paradigm shift (Kuhn and Hacking 2012) is needed to reach a state of broad and sustained collaboration between industry and academia (Shapira and Rosenfeld 2010) – defining what constitutes theory, under-
standing professional cultures, formulating key needs and brainstorming ways to address them, and creating impetuses for collaboration. The Seattle 2014 event was intended as an incubator for such change.

**RESEARCH OBJECTIVES**

The formal approach of the event was designed to address three critically important research objectives:

- Overcome the stagnation of construction engineering due to insufficient collaboration of industry and academia on research and education innovations as compared to other disciplines, to advance its overall competitiveness and safer, faster, cheaper, and better quality delivery of its built products;

- Synthesize an actionable interdisciplinary inspired research agenda to investigate important basic questions in construction engineering; moving it from being a passive late-adopter of solutions that emerge in other areas to being at the forefront of innovation by actively engaging in basic research;

- Build a cohort of future leaders in construction engineering research and education among junior and future faculty by facilitating collaboration with practitioners and non-construction NSF researchers, exposing them to critical issues in practice, as well as rigorous scientific approaches of other fields.

**CONFERENCE: BUILDING COLLABORATION AND SUPPORTING FUTURE LEADERS**

The Construction Engineering Conference and Research Workshop had the motto ‘leveraging project and career success’ to emphasize a joint commitment of industry and academia to bringing fundamental research to practical fruition. It drew upon the experience of past events by extending networking breaks, extending the event to 2.5 days, and reserving the final day for the culminating workshop after a field trip to the tunnel boring at the Alaskan Way Viaduct Replacement project. In addition, there were joint keynotes by senior industry representatives and junior faculty who thus already actively practice
collaboration, and all sessions were structured into a single track to expose all participants to all ideas. Participants had diverse expertise:

- **NSF stipendees** were young and future construction faculty who hosted NSF researchers, translated construction specifics for NSF researchers, and took discussion notes;
- **NSF researchers** were invited successful non-construction experts from the areas of behavioral psychology, linguistics education, urban development, and industrial engineering;
- **Construction researchers** were faculty who perform scholarly work on various construction topics;
- **Construction industry** representatives collaborated with construction researchers in multiple ways.

The organizing committee solicited participants for the conference and workshop from industry and academia through their networks, augmented by academic and industry associations – the Construction Research Council, the Associated Schools of Construction, the Associated General Contractors, The Beavers – A Heavy Engineering Construction Association, and the Construction Industry Institute.

Each of these activities and types of participant was designed to help build collaboration between industry and academia, per the first objective. At the end of each day the conference held scheduled summary discussions with all participants so that individual insights could be shared with the entire group and discussed across the industry and academic groups. Notably, the NSF researchers acted as facilitators by sharing their external observations with the audience. Benefits included that participants heard of their own area through the interdisciplinary lenses of the NSF researchers, their own immediate reflections were deepened and put into a new context.

The Alaskan Way Viaduct Replacement project field trip juxtaposed researchers and practitioners at a major jobsite, with the goal of stimulating joint conversation and observations that can form future research endeavors. Coincidentally, during the visit the tunnel boring machine of this mega-project was inactive due to having encountered an underground obstacle, which vividly illustrated the complex chal-
lenges that construction engineering practice poses. As noted below, 49% of the workshop participants reported to have started new collaborations that grew from the networking, interdisciplinary discussions, and group activities from this event, which demonstrates the success of the various activities.

**WORKSHOP: BASIC RESEARCH IN CONSTRUCTION ENGINEERING**

As described in the workshop agenda (provided in the Appendix), the workshop had three fundamental components. These included 1) Understanding the Importance of Basic Construction Research, 2) Fundamental Research Questions in Construction, and 3) Approaches to Investigate Solutions for Construction Engineering. It applied best practices from the engineering and education literature to design and administer effective workshops, e.g. “[i]ncorporating non-academic voices [here industry representatives] in research design and dissemination” (Salsberg *et al.* 2012, p. 189). Best practices included that participants lead steps in small groups followed by synthesis (Taylor *et al.* 2011); providing pre-workshop materials and collecting post-workshop evaluations (Steinert *et al.* 2008); connecting the “driving and restraining forces” with “action areas” for different stakeholders and soliciting feedback in each step (Barrett 2007, p. 271); communicating “clearly defined objectives” at the start and throughout (Wlodkowski 1997, p. 22); and using steps of “opening [;] prior knowledge [;] exploration [;] reflection [; and] application” (Morrow and Dusenberry 2004, p. 2155).

Workshop attendees comprised seven full (11%), five associate (8%), and 34 assistant professors (55%), one staff researcher (2%), 14 Ph.D. students and candidates (23%), and one industry representative (2%) for a total of 62. By design the target populations of junior and future researchers made up the two biggest percentages among the large group of constituents from whom knowledge was captured. A shortfall was a disappointingly low attendance by industry, despite good industry representation during presentations. However, the enthusiasm of this individual emphasizes the importance of broadening in-
dustry participation in future events. Two former NSF program directors of the Civil Infrastructures Program within the Directorate for Engineering participated as members of the organizing committee and also graciously agreed to co-lead the workshop alongside the first author. As a key component of the workshop, these former program directors delivered a presentation on strategies for writing successful NSF proposals. Definitions for basic versus applied research were discussed and illustrated with an anecdote, along with four types of research objectives as testing a hypothesis; measuring a parameter; prove a conjecture; or adopt an external method (Hazelrigg 2007). Participants heard about the Intellectual Merit and Broader Impact criteria of NSF, and saw sample formats for research questions. These strategies were later put to use as participants developed preliminary proposal ideas founded in the results of the collective brainstorming on basic research needs that is further described below.

WORKSHOP DATA COLLECTION

The purpose of the workshop was to elicit detailed knowledge from experts in and beyond the construction engineering community. As the goal was to aggregate many diverse views rather than to impose preexisting notions of the event moderators, qualitative data were collected in written form as follows:

- Individual questionnaire responses after sharing preparatory reading material with attendees;
- Team responses noted down by scribes from group brainstorming sessions during the workshop;
- Individual feedback by attendees on preliminary results and draft research agenda *a posteriori*.

Participants were asked to individually complete worksheets *a priori* (see Supplementary Data), then to collaboratively brainstorm and synthesize information during the event. They were grouped into teams, with a senior experienced faculty member assigned as facilitator. Teams generated responses to prompts that were subsequently presented at the workshop. Finally, teams collaboratively outlined a research proposal using questions that they had generated, which was shared as well. Work was captured on large
notepads to facilitate group summaries. Notepads and 31 worksheets were collected for analysis. Once
the qualitative output was aggregated, participants were asked to review it and provide comments.

WORKSHOP DATA ANALYSIS

Written data were digitized, transcribed, and labeled with analytic attributes. These documents com-
prised text as well as coloration, lists, tables, diagrams, and flowcharts. Next they were imported into
*NVivo* (QSR 2012), a qualitative coding software package. An emergent coding scheme (Saldaña 2009,
miles and Huberman 1994) was used to represent the data. In other words, participant vocabulary and
phrases defined qualitative codes; each code represented a category that participants had identified. For
example, “*research on response to accidents,*” “*what are main factors contributing to construction haz-
ard,*” “*sources of safety risk in construction,*” or “*why struck by injuries continue as problem*” were cod-
ed under *safety.* Codes also reflected questions to which the participants responded. For example, one
team identified “*lack of systemized information post cost, cost profit*” as a barrier to basic research. It
was generalized under a barrier *lack of data* and also coded as the research need *cost.*

After an initial review, the second author conducted two independent coding iterations of the entire
dataset. This ensured that codes were applied consistently throughout the dataset; no additional codes
emerged during the second coding pass. After these iterations, each code was reviewed to ensure all data
were consistent within each code in a check of internal reliability. Next, the codes were grouped into
themes to show trends, commonalities, and differences. Note that participant statements were often ap-
plicable to multiple codes. This means that the quantitative values in Tables 1-3 do not necessarily sum
to the number of participants, teams, or 100%. The first author verified all coding and applied any nec-
essary corrections to the dataset.
RESEARCH AGENDA ANALYSIS

Vignettes summarizing each team’s input were written by the second author to capture its atmosphere and emphasis, which the first author reviewed to fine-tune as needed. At this stage, transcribed individual and team data were still separate, and needed to be fused toward a consensus. In the subsequent analysis step, both authors independently reviewed all data, which had been copied into a single working document. Both authors coded the documents independently to identify major research needs. Afterward, the authors exchanged their work and consolidated the needs into one list, which formed the draft research needs agenda for construction engineering. Finally, the draft was sent to workshop participants for comments, which were incorporated into the final analysis. At that time, participants were asked if (a) the event had deepened their understanding and appreciation of basic research; (b) if it had inspired any new collaborations; and (c) if they planned to engage in more basic research.

WORKSHOP RESULTS

The following bullets list key findings, followed by a discussion of participant responses, including anonymized quotes from participants and relative frequencies that indicate how often items were mentioned.

- Basic construction engineering research questions require both qualitative and quantitative methods;
- Construction engineering is a unique hybrid that encompasses both technical and human factors;
- The construction research community has a strong awareness of the various facets of sustainability;
- The research community seeks to discover fundamental knowledge. It is seen as a means to improve the built environment, serving industry, and supporting sustainability and as a goal in its own right;
- Key barriers and enablers of basic research in construction engineering are identical;
- Industry connections drive more applied research, but also allow collecting data and using results;
The youth of the discipline means existing theory is limited, yet showcases the need for future work;

- Construction complexity, interdisciplinary questions, long project lifecycles, and project uniqueness make construction engineering research particularly challenging but also define this vibrant field.

Types of Basic Research Needs in Construction Engineering

Among the objectives of the event was to identify basic research needs in construction engineering. NSF (2015) defines basic research as “systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind,” whereas applied research is defined as “systemic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.”

Participants provided many explicit examples of basic research, or even wrote sample basic research questions. These were coded by form (how (25 mentions), what (22 mentions), when (zero mentions), where (zero mentions), which (two mentions), who (one mention), or why (12 mentions)). What, which, and who questions seek to define and identify practice-based, methodological, or theoretical problems, component parts, or best practices. How and why questions seek to explain relationships between these identified items.

Importantly, both qualitative and quantitative methods are needed to answer such questions. Many items were written as bullet form rather than as questions. For example, two teams noted the importance of research in construction history (“history + why of safety regulation/practices”). Presumably this includes when and where, which are absent from the counts above due to the form the response was given in. Thus while they gave a total of 200 examples of construction research topics or questions, only 61 are categorized in the counts of question type above. All 200 basic topics and questions are listed in Ta-
Note that while it is comprehensive, this listing is not exhaustive for the area of construction engineering, but rather contains all of those items that were mentioned during the event or feedback on draft results. The topic that was mentioned most often is sustainability with 61 mentions, three times as many as the next most often mentioned, safety. As sustainability was mentioned at such a high rate, when possible its code was divided into economic, environmental, and social sustainability. While frequency is not meant to suggest relative importance of these topics, it does indicate a focus of participants on all facets of sustainability and the unique status of construction engineering as a hybrid research discipline that encompasses both technical and human factors.

<INSERT TABLE 1 HERE>

Major Themes of Importance of Basic Research in Construction Engineering

Participant responses to this question fell into four major themes: Furthering knowledge, improving construction delivery, serving industry, and sustainability, which are discussed further below. Table 2 counts mentions across all data, person, and teams who referenced each theme. In general, participants viewed basic research as important for various reasons. Pure science was balanced with a desire to serve society and apply results in both applied research and also directly in the construction industry.

<INSERT TABLE 2 HERE>

Furthering Knowledge

During the event, 18 persons and 6 teams referenced the theme titled furthering knowledge. The text coded to this theme reflects both a desire to build theory and also, as might be expected of an engineering research community, the desire to ultimately use this new theory in applications. These components are discussed next.
Building Theory: 9 persons and 6 teams felt the pursuit of knowledge for its own sake, i.e. pure science, is a worthwhile motivation for basic research. This category included references to “advancing the current body of knowledge,” “underlying constructs” and notes that “basic research provides new ideas and new knowledge”. It is important to emphasize that these comments were not made in the context of defining basic construction engineering research, but rather were specifically intended to answer the question of why it is important. It may be that the status of engineering as an applied science led many respondents to give a reason for why the pursuit of pure knowledge was important. In any case, the reasons given noted that theory is “generalized” and as such can “translate to solve many problems”. These responses further referenced the “changing nature of construction” that makes theoretical understanding important. In addition, respondents felt that the pursuit of pure knowledge will permit transformative or “revolutionary change” rather than just incremental progress in construction practice. Respondents noted an obligation “to become proactive”, or “instead of following – develop and build a novel path”.

Solving Problems: 12 persons and 4 teams mentioned problem-solving as motivating basic research (“allows us to address one of the fundamental presenting industry problems”). This reflects a tension of natural to engineering research; even while pursuing pure knowledge there is a strong awareness of and dedication to its use. A strong current in this theme (6 persons and 3 teams) was the desire to “prepare for future problems” and “avoid shortcomings before they happen”. It is noteworthy that more individuals but fewer teams mentioned problem solving as compared to pure science. This suggests that problems referenced were theoretical. It may also reflect a hierarchy in motivations. In other words, some participants may have felt that the true motivator for basic research in construction is its ultimate application, but still recognized an important intermediate step of basic research. For example, one respond-
ent wrote that basic research is “answering a scientifically interesting question that gives us an outcome that can then be applied”. Ultimately generalizable theory was seen as important, either for its own sake or for its ultimate application. Indeed, this theme was referenced by more persons than any other (18), and ties with Sustainability (discussed below) for being referenced by the most teams (6).

Improving Construction Delivery

10 persons and 5 teams referenced a specific improvement of construction delivery as a motivator for basic research. Of those numbers, 6 individuals and 4 teams noted improving the construction process (such as “improving productivity,” “construction is the least efficient industrial sector” or “safety”). Similarly, 4 persons and 4 teams noted needs to improve outputs (infrastructure “resilience to changing conditions”, or “more user-friendly to enhance safety”). These references are closely related to the general problem-solving that was discussed above. However, since these motivators for basic research are solely practical (rather than a combination of practice and theory) they are presented here separately.

Serving Industry

Recognizing those engineers who deliver civil infrastructure, participants noted the importance of serving industry. 12/31 persons and 5/7 teams cited it in form of engineering education (“to better prepare construction professionals”), national pride (“US competitiveness”), and again solving problems (“industry wide fundamental problems”). An important group of comments in this theme described basic research as the “foundation for applied research.” This theme is linked to the practical side (see Furthering Knowledge), but also to process and output improvement (in Improving Construction Delivery). Yet serving industry is not the only motivator for performing research, as is discussed under Sustainability.
Sustainability

A Sustainability theme emerged in the data from 9 persons and 6 teams. Some respondents did not specify any type that motivated them; others specified the triple bottom line of “economics, environment, social”. As this definition of sustainability represents the specific types mentioned, the discussion here also follows this breakdown. It must be emphasized that these references to sustainability were in direct reference to the question of why basic construction engineering is important. Sustainability also emerged as an unresolved fundamental research question for the field, and was incorporated under that aspect.

Economic: Economic sustainability was listed by 2 persons and 4 teams as motivating basic construction research. Half of these referred directly to “life cycle cost efficiency.” One referred to limited resources and the final two merely stated “economics.” In contrast, 18 mentions were made to economic sustainability (also often referencing life cycle cost) when the discussion moved to examples of important research questions (as opposed to why basic research is important in construction engineering). This may be due to understanding economics as an enabler of other goals, rather than as itself a desired outcome.

Environmental: Just 1 person and 2 teams referenced environmental sustainability as a motivator for basic research. Two references were made in a list of “economics, environment, social” sustainability; the third simply noted “limits” in resources. However, similar to the discussion on economic sustainability, more references (3 persons, 6 teams) were made to environmental sustainability as part of example construction research questions. Mirroring the discussion on economic sustainability, this may suggest that in the context of basic research, environmental protection is seen as a vital tool to provide ecological services to people, rather than as itself a desired outcome. This may be seen as opposed to a deep ecology perspective that prioritizes the environment for its own sake rather than human use (Sessions 1995).
Social: 9 persons and 4 teams cited social sustainability as a motivator for basic research, noting “positive social impact”, managing “cultural changes”, “social needs tied to construction understanding”, and “infrastructure to support society”. In comparison, fewer people (4) but more teams (5) noted it in the discussion on construction engineering research questions (described later herein). This again suggests that serving society and industry is seen as the key motivator of construction engineering research.

**Barriers and Enablers to Performing Basic Research in Construction Engineering**

A headline finding is that the identified key barriers and enablers of basic research in construction engineering are the same. Industry involvement drives researchers towards applied rather than basic research, but also ensures the relevance of our work. The youth of the discipline means we face limitations in the existing body of knowledge, but also leaves great opportunity for advances in knowledge. Finally, the defining features of our discipline (such as long project lifecycles, complexity, or unique projects) challenge existing research methods, but also define our area of interest.

**Barriers**

Six categories of barriers that hinder basic construction research were identified by participants. While only 14 persons identified a barrier on the individual worksheets, all seven teams responded to this item. Figure 1 was developed to represent the collective wisdom that the workshop participants generated. Its relationships were mapped from actual responses with implied cause-effect directions as far as could be discerned. They are discussed in the following paragraph and are acknowledged to not be intended to exclude other possible dependencies. Further research may refine the understanding of these barriers.
The short history of construction engineering means that its status quo shows a precedent of applied research, a lack of theory, and a lack of accumulated data. Inherent characteristics, such as unique projects, long lifecycles, and complex subjects, have led to a lack of theory and data, and interdisciplinary research questions, such as those described in the following. A tight focus on technology in past research means there is a lack of existing theory to address pressing interdisciplinary questions. This precedent results in funding challenges that are common to interdisciplinary research. The excellent relationship with industry of the research community (industry also appears as an enabler) has resulted in funding that pushed the academic community towards applied research and away from basic research. Moreover, due to liability concerns and confidentiality requirements, data and research results may not always be accessible nor discoveries publishable. A history of applied research also creates normative pressures to continue. Being a young discipline means less existing theory to build upon and less sources of funding.

Enablers

Only 7 persons and 4 teams listed enablers for basic construction engineering research; other participants declined to answer this question. Interestingly, enablers mirror the identified barriers. While inherent challenges such as unique projects and construction complexity make research difficult, they also generate interesting questions for the research community to answer; it is a “rich topic field.” Interdisciplinary work is becoming increasingly important, creating “opportunities for interdisciplinary research”. Funding is seen as a challenge, but possible to achieve; NSF was identified as the best source. While the discipline is young, there are currently more tools, research methods, and theories than have ever existed in the past. This implies an exciting future for the discipline. Finally, while the close connection of the research community to industry presents challenges for basic research (such as pressure
towards more applied topics), it also means that results are implemented and that data are both collect-
ble and relevant.

Feedback from Non-Construction Researchers

The non-construction researchers provided written feedback on the event. Like other participants, they
felt interdisciplinary collaboration would be valuable for the construction research questions discussed.
One of them extended this idea of interdisciplinary focus to education, suggesting that the construction
community should make developing soft skills both targeted and systematic. Another suggested an NSF-
sponsored mentor program for junior faculty in construction engineering. Two noted the need for con-
tinued careful research design and validation of results. Two suggested that the concept of translational
research (rather than the dichotomy of basic versus applied) is a valuable perspective for the community.
The non-construction researchers also noted the need for the next generation to define “tightly-defined
individual research areas” to advance construction research both individually and as a community. Be-
yond the advice given by the non-construction researchers, many of the various research topics identi-
fied throughout the workshop would benefit from interdisciplinary collaboration. Specifically, they not-
ed that there exist aspects of construction engineering that are also investigated by non-construction re-
searchers, for example information management, systems analysis, organizational structures, perfor-
ance measurement, risk management, and others. Interestingly, the psychologist noted that both his
field and construction engineering operate with a ‘science-practitioner’ model. Both the interest of the
attending non-construction researchers and individual experiences shared by workshop participants sug-
gest that insights and methods developed in other fields can be extremely useful in construction re-
search.
RESEARCH AGENDA

As described under Research Agenda Analysis, the agenda for basic research in construction engineering emerged as a call for action to be addressed collaboratively by construction academia and industry:

Research Agenda Part 1: Global Systems and Sustainability

- Creating and maintaining vast distributed infrastructure systems (for example, through research treating mega-projects or issues of distributed technology)
- Fostering life-cycle efficiency and productivity in processes and operations (for example, through research treating lean construction, supply chain, efficiency, productivity)
- Accommodating global societal growth, policy trends, environmental issues, and other changes (for example, through research treating climate change, interplanetary construction, or global projects)
- Defining, measuring, incorporating, and enhancing sustainability (for example, through research treating social, environmental, and economic sustainability topics).

Research Agenda Part 2: Technology and Management

- Designing for the hybrid technical-human nature of construction engineering (for example, through research treating organizational theory or skilled labor and workforce issues);
- Broadening avenues of adoption of advanced technologies and interdisciplinary innovations (for example, through research treating biomimicry or parsing big data);
- Exploiting integrated and immersive information technology and data sensing (for example, through research treating cyber-security, visualization, or sensors);
- Enhancing safety and mitigating internal and external risks (for example, through research treating site safety, uncertainty, risk avoidance and mitigation, or decision support systems);
Defining, measuring, planning, controlling, analyzing, and optimizing interrelated managerial dimensions (for example, through research treating planning, quality, scheduling, contracts, cost, and project delivery, using simulation, game theory, and other techniques).

Research Agenda Part 3: Research Methodology

- Efficiently considering challenges of project complexity, uniqueness, and longevity;
- Introducing mechanisms for increasing industry participation during research progress;
- Adapting interdisciplinary research methodologies to derive generalizable new theories;
- Establishing benchmark datasets and performance metrics to test new theories and models.

Participant Assessment

Of the 62 workshop participants, the co-authors, conference chair, and two former NSF directors were excluded from this assessment, leaving 57 non-organizer participants, of whom 41 (69%) responded. Table 3 lists responses, which were grouped by tendency and level of detail. Participants unanimously agreed on the value of the event toward their understanding of basic research. An encouraging 49% indicated that they had – to various degrees – embarked upon new collaborations, while another 29% were hoping to do so in the future. Even more, a combined 75% were intending to engage in basic research.

Among the detailed responses to the first question, it was emphasized again to embrace an interdisciplinary approach. Multiple participants underlined the value of tracing basic research from needs to sample proposal ideas. Regarding new collaborations, multiple proposals under development, including interdisciplinary ones, were described, whose ideas are omitted here due to potentially being pending for funding or publication. They echoed themes that have been described above. In terms of plans for basic
research, respondents also provided details across multiple agenda items. In other words, the research agenda has not merely been proposed, but is in fact already being actively used to guide basic research.

<INSERT TABLE 3 HERE>

**Limitations and Future Work**

The research agenda presented here is not a static creation. As time passes, the construction engineering community will need to continue to build on this and past efforts to shape the future direction of this area, while actively pursuing the basic research needs that have been identified herein. The authors suggest that future forums to facilitate this conversation, in print or in person, is of great importance. One limitation of the Seattle workshop was that, by design, it focused on relatively new members of the research community. Future events that facilitate the involvement of more senior members alongside their junior colleagues within the community are important. A limitation of this most recent effort was the low rate of industry participation in the workshop. Workshop organizers inquired as to the reasons for this low participation; extremely heavy professional travel requirements, project supervision demands, and personal conflicts were mentioned in response. While senior industry professionals managed to attend the day when they were presenting together with their academic coauthors, they could not spare additional time. Future workshops might try to mix conference and workshop activities so that industry members who can only attend a single day have the opportunity to attend some of each. It is also recommended to use one registration, fee, and advertisement for the entire event to clarify that the ‘research’ part is not only intended for ‘researchers’ and that it is one integrated event comprising of conference and workshop components.

Finally, many of the terms that emerged during analysis – such as sustainability, complexity, human factors, or resilience – have different definitions depending on which literatures researchers ground
themselves in. The organizers did not define these terms for participants to avoid biasing the discussions. However, future efforts to define such terms with specific relevance to construction engineering will be important undertakings.

CONTRIBUTIONS

Construction engineering provides the means and methods to design and execute built facilities and is a major contributor to the national economy. Improvements in project performance through basic research are urgently needed (NRC 2009) to achieve the practical and theoretical goals described in this article. As a step towards meeting this need, the 2014 Construction Engineering Conference and Research Workshop assembled a high caliber group of researchers to work toward identifying ways of the industry. It shows a collective vision of the future of the construction engineering discipline, founded on collaborative research to address critical real-world problems by deploying rigorous scientific approaches.

Specific contributions to the body of knowledge are an explicit basic research agenda for construction engineering itself. It calls on academia and industry to collaboratively develop their specific research projects to address global systems and sustainability (for example, creating and maintaining vast distributed infrastructure systems), technology and management (for example, designing for the hybrid technical-human nature of construction engineering), and research methods (for example, adapting interdisciplinary research methodologies for construction engineering research). Second, it fosters an interdisciplinary view of construction engineering, by having embedded for the first time a group of non-construction researchers from backgrounds as diverse as behavioral psychology, linguistics education, urban development, and industrial engineering into the entire event. Finally, the detailed documentation of the conference and workshop can serve as a template for events in future decades to update the agenda and measure accomplishments.
ACKNOWLEDGEMENT

The support of National Science Foundation grant number CMMI-1353242 (PI: Gunnar Lucko) for portions of the work presented here is gratefully acknowledged. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

The authors would like to thank the workshop hosts, Dr. Jesús M. de la Garza, NAC, Virginia Polytechnic Institute and State University and Dr. Edward J. Jaselskis, PE, NAC, North Carolina State University for graciously sharing their time and expertise on basic research, as well as all other members of the organizing team, including Dr. John E. Schaufelberger, PE, NAC, University of Washington, Conference Chair; Dr. Paul M. Goodrum, PE, University of Colorado at Boulder, Proceedings Editor; Dr. Clifford J. Schexnayder, PE, Arizona State University; and Dr. Clyde B. Tatum, PE, NAC, Stanford University for making the event a reality. Last, not least, thank you to the NSF researchers, Dr. Erin F. Haynes, Dr. Jack D. Kartez, Dr. David J. Mendonça, and Dr. Sigurdur O. Sigurdsson for venturing into a new knowledge area and sharing their interdisciplinary views.
2014 Construction Engineering Conference
National Science Foundation Workshop:
Promoting Basic Construction Research
Saturday, March 29, 2014

Contents

- Workshop Agenda
- Step 1: Understanding the Importance of Basic Construction Research
  (Understanding the fundamental role and components of ‘theory’ in construction engineering in all aspects of its project delivery, obtaining the inspiration from non-construction research areas and considering explicit and implicit barriers as well as internal and external enablers as a path to transform the construction industry)
  - “Honing Your Proposal Writing Skills,” by George Haze
  - NSF Basic Research
- Step 2: Fundamental Research Questions in Construction Engineering
  (Identifying unsolved fundamental research questions in construction engineering and opening minds to interdisciplinary approaches to solve such needs)
  - “2012 Civil Infrastructure Systems Research Workshop,” sponsored by NSF
  - New Ideas Worksheet
- Step 3: Approaches to Investigate Solutions for Construction Engineering
  (Exploring interfaces of social/behavioral, computing, and technological systems that shape means and methods, life cycles, and construction engineering performance, e.g., its time, cost, quality, safety, and sustainability), to overcome traditional paradigms and assumptions toward a holistic view
  - Proposal Development Guidelines
- List of Attendees

Note: Some preparation for this workshop is required—see information found in Steps 1 and 2.
Step 1: Understanding the Importance of Basic Construction Research

Understanding the fundamental role and components of ‘theory’ in construction engineering in all aspects of its project delivery, obtaining the inspiration from non-construction research areas and considering explicit and implicit barriers as well as internal and external enablers as a path to transform the construction industry

- Prior to Workshop
  - Read “Honing Your Proposal Writing Skills” by George Hazelrigg
  - Think about:
    - What is basic construction research?
    - Why is this type of research important to the construction field?

What are the barriers and enablers for performing basic construction research?

Step 2: Fundamental Research Questions in Construction Engineering

Identifying unsolved fundamental research questions in construction engineering and opening minds to interdisciplinary approaches to solve such needs

- Prior to Workshop
  - Review results from the “2012 Civil Infrastructure Systems Research Workshop” sponsored by NSF
  - Think about:
    - What basic research needs exist?
    - What solutions in form of ideas, principles, theories, systems, or products could address them?
    - How to barriers and enablers interact with them?

- To be completed during workshop
  - Use “New Ideas Worksheet” provided

New Ideas Worksheet: Step 1

- What is basic construction research?
  - Establish a definition of basic research as a group.
  - List examples of basic research that illustrate the definition.

- Why is this type of research important to the construction field?
  - Brainstorm reasons of why it is not sufficient to just perform applied research.

- What are the barriers and enablers for performing basic construction research?
  - Brainstorm what barriers exist (factors that are challenges or obstacles of cultural, political, economical, environmental, technological, or other nature).
  - Brainstorm what enablers exist (factors that are opportunities or facilitators of cultural, political, economical, environmental, technological, or other nature).

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Type / Description</th>
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<table>
<thead>
<tr>
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<th>Type / Description</th>
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</tbody>
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New Ideas Worksheet: Step 2

- **What are unsolved fundamental research questions?**
  List ideas of research needs from discussion at the end of each conference day.

- **What are potential solutions to the aforementioned research needs?**
  List ideas, principles, theories, systems, or products that could address needs.

- **How do barriers currently prevent performing basic research to solve needs?**
  Match specific barriers with needs (multiply may apply).

<table>
<thead>
<tr>
<th>Specific research need</th>
<th>Potential solutions</th>
</tr>
</thead>
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<tr>
<td></td>
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<td></td>
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</tbody>
</table>

Use color stickers to rank importance of research needs as identified by group.

Step 3: Approaches to Investigate Solutions for Construction Engineering

Exploring interfaces of social/behavioral, computing, and technological systems that shape means and methods, life cycles, and construction engineering performance (e.g., its time, cost, quality, safety, and sustainability), to overcome traditional paradigms and assumptions toward a holistic view.

- **To be completed during workshop**

Proposal Development Guidelines
Proposal Development Guidelines

- Proposed Title:
- Research need fulfilled:

- Proposed idea, principle, theory, system, or product:
- Barriers and enablers to successful performance:

- Proposed research team:
- NSF or other agency program solicited for funding:

- Intellectual Merit (in bullet format):

Broader Impact (in bullet format)
REFERENCES


QSR (2012). *NVivo*. Qualitative data analysis software, QSR International (Americas), Burlington, Massachusetts.


Table 1: Topics in Basic Construction Research

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<thead>
<tr>
<th>Topic</th>
<th>Mentions</th>
<th>Topic</th>
<th>Mentions</th>
<th>Topic</th>
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<td>Planning</td>
<td>6</td>
<td>Biomimicry</td>
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<tr>
<td>Sustainability (Social)</td>
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<td>Productivity</td>
<td>6</td>
<td>Construction History</td>
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<td>Safety</td>
<td>21</td>
<td>Resilience</td>
<td>6</td>
<td>Efficiency Energy</td>
<td>2</td>
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<tr>
<td>Labor or Workforce Issues</td>
<td>19</td>
<td>Visualization</td>
<td>6</td>
<td>Organizational Communication</td>
<td>2</td>
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<tr>
<td>Sustainability (Environmental)</td>
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<td>5</td>
<td>Technology</td>
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<td>Equipment</td>
<td>5</td>
<td>Contracts</td>
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<tr>
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<td>Quality</td>
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<td>BIM</td>
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<td>Management</td>
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<td>Mega Projects</td>
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<td>Organizational Networks</td>
<td>3</td>
<td>Why do we build as we do</td>
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<td>Sensors</td>
<td>7</td>
<td>Supply Chain</td>
<td>3</td>
<td>Why do we build so much</td>
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<tr>
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<td>Automation</td>
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Table 2: Why is Basic Construction Engineering Research Important?

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<td>1.2 Solving Problems</td>
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<td>1.2.1 Avoid Unidentified Problems</td>
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<td>3</td>
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<td>2. Improving Construction Delivery</td>
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<td>5</td>
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<td>2.1 Process</td>
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<td>6</td>
<td>4</td>
</tr>
<tr>
<td>2.2 Product or Outputs</td>
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<td>4</td>
<td>4</td>
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<tr>
<td>3. Serving Industry</td>
<td>29</td>
<td>12</td>
<td>5</td>
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<tr>
<td>3.1 Basis for Applied Research</td>
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<td>5</td>
<td>3</td>
</tr>
<tr>
<td>4. Sustainability</td>
<td>28</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>4.1 Economics</td>
<td>6</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4.2 Environmental</td>
<td>3</td>
<td>1</td>
<td>2</td>
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<tr>
<td>4.3 Social</td>
<td>17</td>
<td>9</td>
<td>4</td>
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* Counts are additive within each theme.

** Includes multiple instances for a Person or Team.
### Table 3: Workshop Assessment by Participants

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<th>Survey Question</th>
<th>Yes (Details)</th>
<th>Yes</th>
<th>Not Yet</th>
<th>Already</th>
<th>No</th>
<th>Total</th>
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<td>1. Did the workshop deepen your understanding and appreciation of basic research for construction engineering?</td>
<td>27 66%</td>
<td>14  34%</td>
<td>0 0%</td>
<td>0 0%</td>
<td>0 0%</td>
<td>41 100%</td>
</tr>
<tr>
<td>2. Have you started any new collaborations based on the discussions and exercises of the workshop (please explain)?</td>
<td>20 49%</td>
<td>0  0%</td>
<td>12 29%</td>
<td>1  2%</td>
<td>8 20%</td>
<td>41 100%</td>
</tr>
<tr>
<td>3. Are you planning to engage in (more) basic research for construction engineering in the future (please explain)?</td>
<td>21 51%</td>
<td>10 24%</td>
<td>4 10%</td>
<td>3  7%</td>
<td>3 7%</td>
<td>41 100%</td>
</tr>
</tbody>
</table>
Figure 1: Barriers to Basic Research in Construction Engineering
Figure 1: Barriers to Basic Research in Construction Engineering

Table 1: Topics in Basic Construction Research

Table 2: Why is Basic Construction Engineering Research Important?

Table 3: Workshop Assessment by Participants
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Journal of Construction Engineering and Management

Publication Title: Journal of Construction Engineering and Management
Manuscript Title: Construction Engineering Conference and Workshop 2014: Setting an Industry-Academic Collaboration Research Agenda

Authors - Names, postal addresses, and email addresses of all authors
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<td>Technical Paper/Case Study = 8 pgs.</td>
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<td>Technical Note = 3 pgs.</td>
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<th>Construction Engineering Conference and Workshop 2014: …</th>
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<tr>
<td>Journal name:</td>
<td>Journal of Construction Engineering and Management</td>
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<tr>
<td>Corresponding author name:</td>
<td>Dr. Gunnar Lucko</td>
</tr>
<tr>
<td>Email address:</td>
<td><a href="mailto:lucko@cua.edu">lucko@cua.edu</a></td>
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Department of Civil Engineering, Catholic University of America
Pangborn Hall Room G-17, 620 Michigan Avenue NE
Washington, DC 20064

September 22, 2015

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Reston, VA 20191

To Whom It May Concern: Please find enclosed the accepted minor revisions for technical paper manuscript “Construction Engineering Conference and Workshop 2014: Setting an Industry-Academic Collaborative Research Agenda” by Gunnar Lucko and Jessica A. Kaminsky in the Industry Forum specialty area of the Journal of Construction Engineering and Management.

Comments from the Editors and Reviewers: The authors have responded to reviewer comments and manuscript is ready for publication as a technical paper. The authors should consider making the changes suggested by Reviewer #1 below. Thank you, we have done so.

Reviewer #1: 118 joint keynotes by senior industry representatives and junior faculty to already actively practice collabo
Believe it should be: joint keynotes by senior industry representatives and junior faculty who already actively practice collabo
Thank you, done.
127 The organizing committee solicited participants for the conference and workshop from industry and ac
128 ademia through their networks, augmented by academic and industry associations - the Construction
129 Research Council, the Associated Schools of Construction for faculty, the Associated General Contrac
130 tors, and the Construction Industry Institute.
Need to add the The Beavers, Inc. to this list. Thank you, done.
141 inactive due to having encountered an underground obstacle, which vividly illustrated the complex chal
142 lenges that construction engineering practice poses. As noted below, 49% of the workshop participants
Need to change the statement: “to having encountered an underground obstacle”.
Maybe something like: inactive due to construction environment issues. This vividly illustrates the complex challenges that
construction engineering practice poses. The authors respectfully wish to retain the original phrasing, as it is more specific.
Reviewer #2: Please include detailed comments to the author in this box. Not applicable

Should you need to contact me, you can reach me via email at lucko@cua.edu or fax at 202-319-6677.
Thank you very much.

Sincerely,

Gunnar Lucko, Ph.D.
Associate Professor and Director, Construction Engineering and Management Program