Teaching Architecture

Insights from TU Delft – Research on Education Innovation in Architecture & the Built Environment

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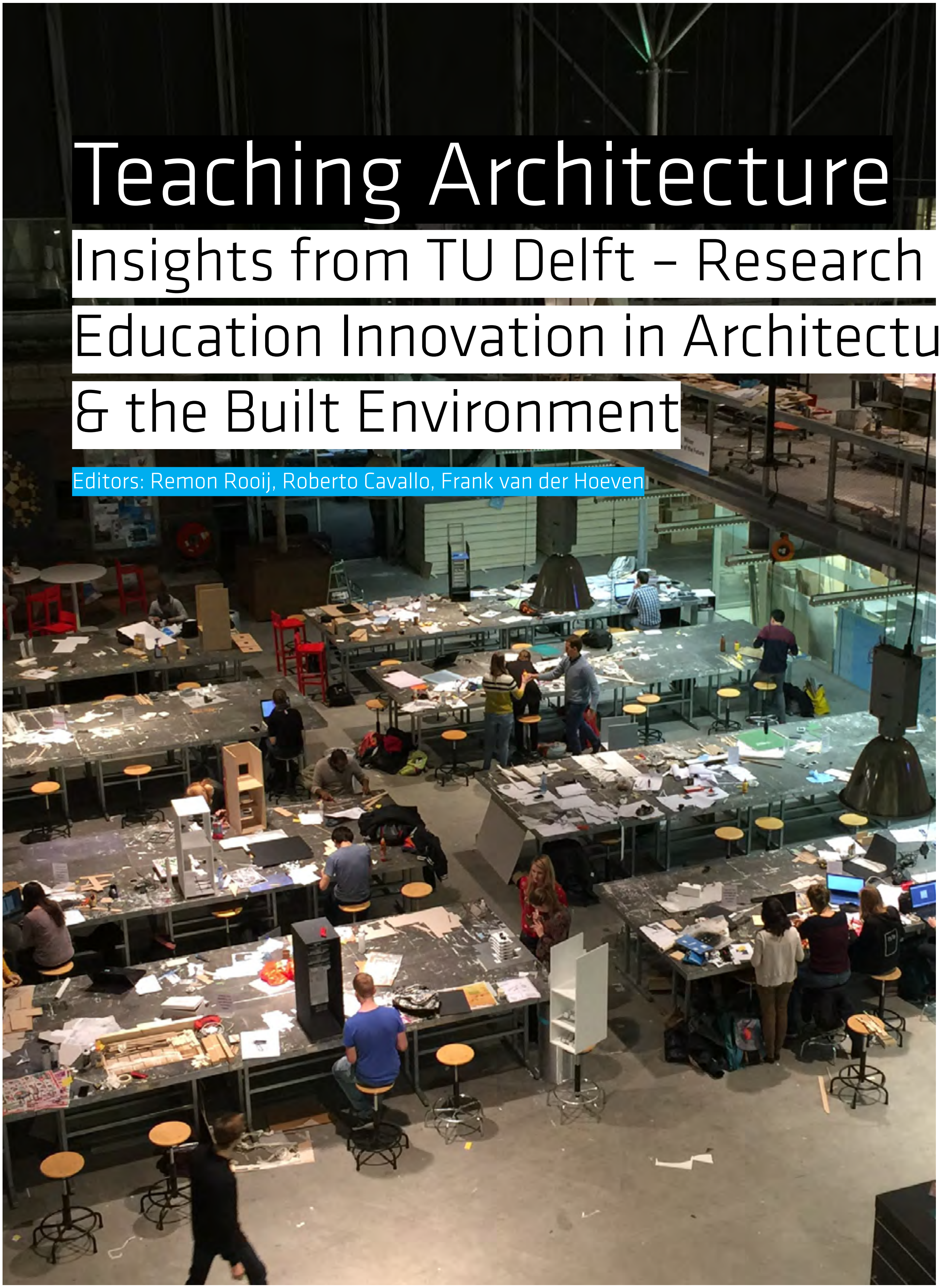

Interdisciplinary design education in the field of urban infrastructure

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Abstract

Building resilient urban infrastructure that can anticipate the challenges that come with climate change needs an interdisciplinary approach. Deviating from the paradigm of engineering protection can only be done when the spatial context is integrated. Yet, interdisciplinary cooperation between civil engineering and spatial design, fields with very different cultures and languages, has been protocolized to a multidisciplinary collaboration over time. In order to change this Delft University of Technology incorporated interdisciplinary design into its MSc-level education of civil engineers and spatial designers. Taking challenges in Japan, which have been subject to storm surge and tsunami hazards, Albania, the United States, and Ghana, all of which suffer from pluvial, fluvial, and coastal flooding proved solid learning grounds. The interdisciplinary design projects, organised for students from various disciplines, were set up to learn from and perform the hypothetical redesign and reconstruction of areas in flood plains, aiming to increase disaster resilience and liveability.

The participating students were asked to evaluate their projects to be able to assess the effectiveness of the Tohoku interdisciplinary design method and discuss lessons learned for interdisciplinary projects with engineering and design students. The results show that the interdisciplinary project provides engineering students with more broad and practical experience of the sort that has been lacking in the decades since engineering education came to be dominated by academic researchers rather than practitioners. On the other hand, students in architecture and urbanism viewed this opportunity as a chance to apply their already acquired integrative skills in an interdisciplinary setting.

Keywords

Interdisciplinary design, urban infrastructure, sustainable development

COVER FIGURE A photo series representing the different disciplines of interest in the reconstruction of Otsuchi after the tsunami disaster 2011. By (from top to bottom and left to right) Jochem Roubos (structural engineering), Fransje Hooimeijer (urbanism), Frans van de Ven (water management), second to top Aditya Rao (landscape architecture), Jesse Salet (structural engineering), third row Gayatri Mujumdar (urbanism), Eline van Unnik (transport planning), fourth row Ilse Nederlof (water management), Nataly Filipouskaya (geo engineering) .

1 Introduction

The call for a more conscientious and integrated design process in urban infrastructure design stems from the realisation that increasing the resilience of the built environment is essential for enduring natural disasters (Amirzadeh et al., 2022). Cutter et al. (2008) contend that achieving this resilience necessitates multidisciplinary collaboration (the assembly of the team), culminating in interdisciplinary design (the result of the work by the team). The partnership between the civil engineering and spatial design disciplines presents significant hurdles, with one of the primary challenges arising from differences in terminology, starting with the very definition of 'design'. In its broadest interpretation, design serves as a methodology to discover common ground in situations where measures, problems, and objectives remain undefined (Van de Ven et al., 2009). However, engineers are accustomed to employing an optimisation methodology when designing solutions, whereas spatial designers adopt a research-by-design approach. These distinct fields operate under different paradigms and problem-solving rationales (see Table 1).

MEASURES	PROBLEMS AND GOALS	
	FAMILIAR / EXISTING AGREEMENT	UNFAMILIAR / NO AGREEMENT
Known	Optimisation	Negotiation
Unknown	Innovation	Design

TABLE 1 Solution strategies for different types of problem (Van de Ven et al., 2009, derived from Thompson and Tuden, 1964)

According to Webber and Rittel (1973), engineers commonly confront 'tame' problems, whereas spatial designers grapple with 'wicked' problems. This dichotomy underscores a disparity between the pursuit of the most efficient solution to a problem (which is tame) and the endeavour to identify the most contextually appropriate solution within complex societal systems lacking clearly defined boundary conditions (which is wicked). Webber and Rittel (1973) identify the transition away from the notion of efficiency in the late 1970s with the reintroduction of the urban context with complex societal systems within the problem solving.

A similar change has also occurred in engineering education, a field dominated by a research-focused from the 1980s onward (Crawley et al., 2007). This shift has pushed students toward more focused, fundamental knowledge with less emphasis on application or group work skills. Moreover, the introduction of the computer brought unprecedented calculation capacity that allowed for theoretical system behaviour and exploratory scenario analyses. Prior to this, engineering education had been dominated by practitioners, not researchers, who put more emphasis on project work, learning-by-doing, and testing in practice. Today, industry leaders value the depth of knowledge in modern engineering graduates but bemoan their lack of group work skills, which are necessary for a multidisciplinary working environment (Lang et al., 1999).

Reviewing a range of project-based, interdisciplinary engineering programmes, Mills and Treagust (2003) conclude that students who graduate from traditional engineering programmes have good fundamental knowledge but require extra on-the-job training and experience before they can function productively in a project setting. In contrast, students from undergraduate programmes with a heavy emphasis on interdisciplinary work struggle with engineering fundamentals and have trouble with core engineering work.

Education in spatial design, encompassing urban design and landscape architecture, emphasises creative design orientation, aiming to harmonise stakeholders' interests in urban projects across all scales. Consequently, it draws from various disciplines and fields of expertise. Unlike engineering, this field is marked by an epistemic culture and depends on a range of scientific disciplines such as engineering, sociology, economics, history, and natural sciences. Within an epistemic culture, each scientific field operates with its own unique methods, instruments, tools of inquiry, and modes of reasoning, as well as methods for establishing evidence (Knorr Cetina, 1999).

Designers traditionally have operated under the assumption that technological advancement could inform any design concept. Consequently, engineering became somewhat separated from this epistemic culture, and creative design has primarily been influenced by social and economic indicators rather than being inherently connected to engineering (Hooimeijer, 2014). However, the current imperative of addressing climate change necessitates reintroducing engineering into the spatial design process to develop the resilient cities of the future.

The main objective of this chapter is to investigate the effectiveness of interdisciplinary design projects for engineering and architecture students to learn how to integrate engineering into spatial design programmes. It presents lessons learned based on interdisciplinary project-based education. The next section explains how interdisciplinarity is incorporated into the educational programmes at Delft University of Technology in the Netherlands and outlines the Tohoku method of interdisciplinary design, named after the region where it was developed. Subsequently, the effectiveness of the programme is discussed and analysed via a survey among participating students. The answers to the questionnaire elaborate on the following topics: multidisciplinary team and interdisciplinary process, role of the engineer, and products of the projects.

2 Interdisciplinary (project-based) education at Delft University of Technology

The review by Mills and Treagust (2003) implies that intradisciplinary (knowledge and skills inside one subject area) education is necessary at the beginning of undergraduate engineering studies to form the foundation of practical knowledge. Further, interdisciplinary education (integrating knowledge from different subject areas) is profitable if applied in upper-year or graduate curricula. Dutch and European university systems traditionally consisted of a five-year programme culminating in the degree of *Ingenieur* (engineer). After the Bologna process (European Commission, 2019), however, EU universities have divided this into a three-year bachelor's (BSc) programme and a two-year master's (MSc) programme. At Delft University of Technology (TU Delft), the first year of the engineering master's programme consists of in-depth courses within each student's chosen discipline, more focused than the broad engineering curriculum of the bachelor's programme. Interdisciplinary education is implemented in the second year of the master's programme, consisting of project course work and graduation thesis research.

For students at the Faculty of Civil Engineering and Geosciences (CEG), the latter is accomplished through a ten European Credits (EC) component that can be done as 'multidisciplinary project group' (MDP) work or as individual research work. Some students also take an interdisciplinary approach to their 40 EC Master's thesis project. In this way, foundational engineering knowledge has already been obtained, and students can apply it in an interdisciplinary setting similar to what they might face in industry, depending on the type of job function they enter. Faculty of Architecture and the Built Environment (ABE) students participate in interdisciplinary groups as part of the Delta Futures Lab (the education platform of the interfaculty research group Delta Infrastructure and Mobility Initiative).

A project-based approach in cooperation with an active case or client is essential to simulate practice, which is interdisciplinary by nature. This structured activity that focuses on participation and interaction is called experiential learning, which allows the learner to create meaning from first-hand experience (Johnston, 2015). It implies a very active learning style experience in how material and principles are encountered, integrated, and applied to new situations (Feinstein et al., 2002).

These collaborations between disciplines are stimulated at TU Delft by dedicating the first quarter of the second year of all MSc tracks to making these connections. Next to working with students in an honours track (excellent and ambitious students adding 20 EC to their study), it is possible to dedicate research courses to this type of work and gather students from the participating faculties in the Delta Futures Lab.

3 Tohoku method of interdisciplinary design[1]

To facilitate an interdisciplinary approach, the regions of Tokyo and Tohoku in Japan (Edogawa, Yuriage, and Otsuchi), Tirana in Albania, Muni-Pomadze Lagoon in Ghana, and Houston in the United States were selected as case studies for multi disciplinary student teams. The projects in the Tohoku region in Japan are foundational for developing the interdisciplinary design methodology, which is why it is called the Tohoku method. Tohoku's coastal cities were devastated by the 2011 Great East Japan earthquake and tsunami, and the region has been rebuilt from scratch using a combination of engineering measures such as seawalls and elevated landfills (Suppasri et al., 2016), natural measures such as coastal forests, and social measures such as land use control, enhanced warning systems, and evacuation drills. This collection of measures allows for the assessment of the physical and social effectiveness of reconstruction measures in real-time, demonstrating whether and how civil engineering and spatial design intertwine.

After the studies in Japan, the student projects shifted to Tirana (Albania), Muni-Pomadze (Ghana), and Houston (USA), locations that are struggling with fluvial and pluvial flooding plus coastal erosion. Solutions for these problems also benefit from an interdisciplinary design approach in which understanding each other's constraints and values not only resolves them but also implements liveable and resilient urban development. Here, the Tohoku method was further developed.

The initial crucial step in the Tohoku method is finding the proper set of disciplines and assigning staff members per discipline to provide intensive guidance. Subsequently, the projects follow the three main phases of the (interdisciplinary) design process: analysis and synthesis, design, and conclusions (Van Dooren, 2013).

1 The methodology description is similar to the paper that is published on these projects but with a focus on the theoretical fundaments of the difference between multi- and interdisciplinary design: Hooimeijer F.L., J.D. Bricker, A.J. Pel, A.D. Brand, F.H.M. Van de Ven, and A. Askarinejad (2022) Multi- and interdisciplinary design of urban infrastructure development. Proceedings of the Institution of Civil Engineers - Urban Design and Planning 2022 175:4, 153-168

During the first phase (analysis and synthesis), the project's conditions and context were established through a series of workshops where participants familiarised themselves with each other and their respective disciplines, as well as a site visit accompanied by lectures to develop a shared understanding of the project. Interdisciplinary conditions were fostered by having students formulate questions within their own discipline, determine inquiries for other disciplines, and identify what contributions they could offer to others. Additionally, an inventory of data and information pertinent to the case was compiled for each field, along with essential background knowledge to be presented to the group.

ANALYSIS AND SYNTHESIS PHASE	CONNECTING WORKSHOP	DESIGN PHASE	CONCLUSION PHASE
Setting interdisciplinary context Making relations between the disciplines Investigation of the context: field trip	1 From an interdisciplinary preliminary group vision on the problem(s) and potential solutions strategies, 2 Form a disciplinary body of knowledge, 3 Define a scope of each discipline applying the same criteria for evaluation, 4 Integrate the scopes in several charette rounds and define the final framework, 5 Connect the framework to the preliminary vision.	Iterations of disciplinary refinement and interdisciplinary integration	Final plan and report

TABLE 2 The sequence of activities in the projects

Two 'in-house' workshops preceded the site visit, during which staff and students visited the site and engaged with stakeholders. The subsequent workshop, conducted during the field trip, entailed a lengthy collaborative session over several days, with the following agenda:

1. Formation of an interdisciplinary preliminary group vision regarding the problem(s) and potential solution strategies, which is crucial for goal integration and determining the best future course for the case.
2. Definition of the shared scope to develop uniform criteria for evaluation along this shared value system.
3. Development of disciplinary knowledge and ideas applicable to the case.
4. Each discipline evaluates its ideas by use of the shared scope.
5. Integration of scopes through several charrette rounds to define the final framework, enabling better insight and understanding of concepts and facilitating connections to proposals from other disciplines.
6. Linking the framework to the preliminary vision to demonstrate the relationship between choices within disciplinary scopes and to provide an interdisciplinary viewpoint on the case.

During this phase, extensive mutual exchange, influence, goal integration, basic integration, and managed integration were established, resulting in a preliminary interdisciplinary design. This design was further developed after the field trip through simulation, evaluation, and decision-making processes. These activities were conducted through alternating disciplinary and interdisciplinary workshops, group meetings, subgroup meetings, and homework sessions. Each discipline refined its proposal component, and the group collectively re-evaluated the proposal to determine necessary refinements. Subsequently, each team member oriented their disciplinary component of the plan toward the final design proposal. The outcomes were presented in a report or scientific paper accompanied by reflections from each team member on the process and project content. Additionally, the group produced a short video presentation showcasing the results of their work.

4 Evaluation of student survey results

To assess the efficacy of this interdisciplinary approach, a survey was conducted among students who participated in the projects, yielding 38 responses. Of these, 66% were involved through project groups, while 34% participated via MSc theses. Even though the latter group only fully engaged in the workshops and site visit activities during the analysis and synthesis phase and then pursued their thesis research, the interaction on the interdisciplinary design level with the multidisciplinary project groups during the design and conclusion phases was very valuable. During these interactions and the presentations of their graduation projects, the collaborative process grew more genuine and intense.

At the time of the survey, 71% of respondents were still students, while 29% had graduated and were employed. Engineering students (CEG) represented various MSc tracks, including hydraulic engineering (HE, 10 students), geo-engineering (GE, 2), transport infrastructure and logistics (TIL, 7), transport and planning (TP, 1), and urban water management (WM, 3). Architecture students (ABE faculty) were enrolled in MSc tracks such as urbanism (U, eight students), landscape architecture (LA, 4), architecture (A, 1), building technology (BT, 1), and management in the built environment (MBE, 1). Among the 38 students surveyed, 2 participated in the 2016–17 Tokyo case, 8 in the 2017–18 Yuriage case, 5 in the 2018 Tirana case, 12 in the 2018–19 Otsuchi case, 5 in the 2019 Ghana case, and 6 in the 2019 Houston case. It is worth noting that certain sub-disciplines were underrepresented, so the subsequent analysis primarily focuses on the faculties involved (architecture and engineering) rather than specific sub-disciplines.

QUESTIONNAIRE: INTERDISCIPLINARY EDUCATION

The first 14 questions are on your background and perspective on collaboration among multiple disciplines.

I-1. How did you participate: Multidisciplinary project student or MSc thesis student?

I-2. Are you a student?

I-3. What is your core discipline? Choose one:

I-4. If you have multiple core disciplines, what do you consider your secondary and tertiary disciplines?

I-5. Which group did you participate in: Tokyo (2016–17), Yuriage (2017–18), Otsuchi (2018–19), Tirana (2018), Ghana (2019), Houston (2019)

I-6. What do you consider to be the core activities of multidisciplinary work? Multidisciplinary working concerns independent, parallel learning assignments of different disciplines. (more answers available) A) open attitude, B) inspiration, C) innovation, D) information integration, E) design, F) communication, G) cooperation, H) co-design, I) exchange, J) bridging, K) confrontation, L) assemblage, M) juxtapose, N) combine, O) synthesise, P) integrate, Q) transcend, Open answer:

I-7. To what degree is *multi*-disciplinarity (parallel learning) addressed during your studies?

I-8. What do you consider the core activities of *interdisciplinary* working? Interdisciplinary working concerns interdependent learning assignments of different disciplines. Same options as question 6

I-9. To what degree is *interdisciplinarity* (interdependent learning) addressed during your studies?

I-10. How easy or difficult was it to 'integrate'/collaborate with the (representatives of the) participating disciplines?

I-11. Which other discipline was the *most useful* to your project/thesis, for example, because it helped to better inform your project?

I-12. Which other discipline did you learn most from, for example, because it changed your perspective on the significance of your project?

I-13. Which other discipline had the *largest impact* on the project, for example, because it determined the boundary conditions or the final goal of your project?

I-14 What disciplines, which would have added value to your project or thesis, were missing from the team?

The next 22 questions are on your perspective on the methodology and results of the overall project.

II-1 How effective was the overall approach in the project (phasing and steps) for disciplinary integration? Answer on a scale of 0–10 (0 = not at all, 10 = extensively)

II-2 How effective was the scoping method used in the workshops for disciplinary integration? Answer on a scale of 0–10 (0 = not at all, 10 = extensively). For example, did it enable you to build arguments for your design choices?

II-3 How effective was the charrette method for the integration of disciplinary knowledge? Answer on a scale of 0–10 (0 = not at all, 10 = extensively)

II-4 What part of the programme was most effective? List them from most to least effective: A. Pre-trip group work in Delft. B. Site visits. C. Group work on-site. D. Post-trip group work in Delft. E. Post-trip group work on the second case. F. Post-trip individual work. Other? (open answer)

II-5 What was the most challenging part of the project? The content (integrating the knowledge), the process (deciding on the steps), the organisation (getting the group together), Open answer:

II-6 What was the most challenging phase of the project? Analysis (learning from the Japan case), synthesis (initial redesign of the Japan case), design (final design worked on after returning to NL), Production of final report/paper

II-7 What was the primary obstacle to working with other disciplines? Vocabulary/concepts (i.e. the meaning of 'design'), perspective, aim/goal, methods, instruments, Open answer:

II-8 Other than the included disciplines, which factors had a significant effect on the effectiveness of the interdisciplinary work process? List in order of influence, with the most important first: size of the group, gender, individual personalities, culture, local counterparts, Open answer:

II-9 According to you, did the interactive group work lead to an interdisciplinary design? Answer on a scale of 0–10 (0 = not at all, 10 = very much): Why? How would you assess that?

II-10 What could be improved to achieve an interdisciplinary design, e.g. the content (integrating the knowledge), the process (deciding on the steps), and the organisation (getting the group together)?

II-11 To what extent did this project enhance your understanding of fundamental principles within your own discipline? Answer on a scale of 0–10 (0 = not at all, 10 = extensively):

II-12 To what extent did you gain broader knowledge that will enable you to work more effectively within your own discipline? Answer on a scale of 0–10 (0 = not at all, 10 = extensively)

II-13 To what extent were you able to achieve your disciplinary aim in the process of the inter/multidisciplinary assignment? Answer on a scale of 0–10 (0 = not at all, 10 = extensively)

II-14 Do you consider this interdisciplinary experience an advantage in your chosen career? Yes, no, why, or why not? Open answer:

II-15 How would you assess the group's performance? Answer on a scale of 0–10 (0 = bad, 10 = good)

II-16 Was it possible to give open feedback to the group members?

II-17 Did you give feedback?

II-18 How would you assess your role in the group? Answer on a scale of 0–10 (0 = minor/passive, 10 = essential/active):

II-19 Which of these four types of roles comes closest to yours? Specialist: how can we optimise technology for better performance using scientific knowledge? Systems integrator: How can we integrate object-oriented parties and systems for a complete solution? Front-end innovator: How can technology contribute towards innovation for (new) industry and society? Contextual engineer: How can we develop and implement technology internationally in society and industry? More answers are possible.

II-20 How would you assess the role of the supervisors? Answer on a scale of 0–10 (0 = confusing, 10 = helpful):

II-21 What do you consider your disciplinary qualities? Open answer:

II-22 What do you consider your disciplinary constraints? Open answers:

Notes on the full survey: The first batch of 14 questions related to students' backgrounds and perspectives on collaboration among multiple disciplines. The next 22 questions related to their perspective on the methodology and results of the overall project. The answers were subjected to a quantitative (I-7, I-I-9 to I-13, II-1 to II-4, II-11, II-12, II-14, II-18, II-20) and a qualitative (I-6, I-8, I-10 to I-14, and II-5 to II-10, II-13, II-15 to II-17, II-19, II-21, II-22) analysis. The evaluation of the survey results focused on 1) the multidisciplinary team and interdisciplinary process of the projects, 2) what roles the students adopted within the multidisciplinary teamwork, and 3) the reflection on the products of the projects.

4.1 Multidisciplinary team and interdisciplinary process

Consulting the survey results about multidisciplinary and interdisciplinary understanding demonstrates that students consider multidisciplinarity a group process and not an outcome, and they highly value communication skills. The students consider interdisciplinarity to be the outcome and intertwining of knowledge and products. Interdisciplinary design equates to the integration of sectoral responsibilities, goals, and solutions.

The quantitative summary of the responses to the survey questions (I-7, I-9 – I-13, II-1-II-4, II-11, II-12, II-13, II-14, II-18, II-20) is shown in Table 4. It shows that both architecture and engineering students thought their knowledge improved. However, architecture students felt they improved more in regard to fundamental knowledge than engineering students, and regarding broader knowledge, engineering students felt they improved at higher rates than architecture students. Engineers felt slightly more than architects that their education up to this point had been multidisciplinary, though architects felt significantly more than engineers that their education up to this point had an interdisciplinary component (questions I-7 and I-9); note the large standard deviations for these items, indicating that individual experience varied greatly.

Engineers felt a slightly more robust sense of achievement from this exercise than architects. At the same time, architects felt that they had a more critical role in the group process than engineers did. This difference may be rooted in how they approach a challenge: engineers are used to fixing a clear problem, while architecture students are problem-seeking and tend to oversee more issues in a challenge. Engineers were more positive than architects that their supervisors played a useful role in the exercise and that the overall programme was effective. The scoping and charrette methods were appreciated overall, and engineering students, in particular, appreciated the process and tools.

All students and recent graduates experienced that the exercise as a whole was (or would be) beneficial for their chosen career for the following reasons:

- International experience
- Experience with developing shared goals
- Practice is multidisciplinary
- Gave insight into their role/added value as a discipline
- Improved communication skills
- Extended their understanding of other disciplines
- Development of a mindset/holistic view
- More grip on how to influence each other in a positive way

Analysing the components of the workshops before, during, and after the site visit, it is evident that, generally, students valued the site visit and the group work during their time on-site (field trip and local workshops over multiple days/one week), designating them the most effective components of the exercise.

	RANGE POSSIBLE		ENGINEERING STUDENTS		ARCHITECTURE STUDENTS	
	MIN	MAX	MEAN	STD DEV	MEAN	STD DEV
II - 11 Fundamental knowledge improved	1	10	6.8	2.2	7.2	1.1
II - 12 Broader knowledge improved	1	10	8.1	1.6	7.9	0.9
I - 7 Multidisciplinary addressed in education	1	10	6.4	2.3	6.0	1.9
I - 9 Interdisciplinary addressed in education	1	10	5.3	2.4	6.3	2.3
II - 13 Sense of achievement	1	10	7.3	1.6	7.1	1.2
II - 18 Role in the group	1	10	7.4	1.6	7.9	1.1
II - 20 Role of supervisor	1	10	8.3	1.1	7.8	1.9
II - 1 Effectiveness of overall program	1	10	7.3	1.5	6.7	1.1
II - 2 Effectiveness of scoping	1	10	7.1	1.6	7.1	1.7
II - 3 Effectiveness of charette	1	10	7.0	1.9	7.1	2.0
II - 4A Effectiveness of pre-trip groupwork	0	5	2.2	1.3	2.7	1.1
II - 4B Effectiveness of site visit	0	5	4.2	1.0	4.5	0.6
II - 4C Effectiveness of groupwork on site	0	5	4.2	1.3	4.4	0.6
II - 4D Effectiveness of post-trip groupwork	0	5	2.9	1.2	3.5	1.1
II - 4E Effectiveness of post-trip groupwork on second case	0	5	2.5	1.6	2.7	1.4
II - 4F Effectiveness of post-trip individual work	0	5	2.8	1.6	3.9	1.2
II - 14 Usefulness of the exercise for your career	0	1	1.0	0.0	1.0	0.0

TABLE 3 Summary of responses regarding the interdisciplinary process

4.2 Survey results: Role of the student within the multidisciplinary team

In question II-19, the student is asked for their role in the team. To simplify this question, the four roles defined by the Free Spirits Think Tank at TU Delft (Kamp and Klaassen, 2016) were used: specialist, front-end innovator, system integrator, and contextual engineer. This classification addresses the idea that the 'Fourth Industrial Revolution' requires engineers who can work in different profiles in vastly diverse contexts and in collaboration with other specialists to create the best solutions for new world scenarios. The specialist provides in-depth technical knowledge to the systems integrator, who brings knowledge of different fields together. The front-end innovator provides information to the systems integrator on emerging human needs and translates these for the specialist into workable research questions. Finally, the contextual engineer and the front-end engineer develop the regulations needed to execute the plan. This process is necessarily iterative. The roles can either shift in emphasis through time, or various people focus on different roles in parallel and work together to understand and solve a societal problem.

An analysis of the outcomes (Table 2) shows that only TIL students consider themselves front-end innovators. Technical innovations are then about logistics and computer engineering. However, due to the wide scope of the TIL programme, they also see themselves in the other three roles. The GE, HE, and BT students consider themselves specialists, which coincides with the type of knowledge they deliver to the projects in understanding the problem (waves, damage) and developing technical solutions (construction, foundations). HE students see themselves as system integrators, just like TP, TIL, WM, U, LA, A, and MBE students. U and A students also consider themselves contextual engineers as they address the interests of stakeholders for an urban project.

	Q19 WHICH OF THESE FOUR TYPES OF ROLES COMES CLOSEST TO YOURS?	Q20 WHAT DO YOU CONSIDER YOUR DISCIPLINARY QUALITIES	Q21 WHAT DO YOU CONSIDER YOUR DISCIPLINARY CONSTRAINTS?
Geo-engineering	Specialist	The ability to integrate the technical constraints, challenges, and solutions of different engineering disciplines into a feasible and effective solution.	The technical jargon, tunnel vision on the small scale/part of solutions
Hydraulic Engineering	Specialist Systems integrator	Analysing, problem-solving, logical thinking and reasoning, attention to detail, creativity and innovation, critical, 'decontextualise-quantify-assess', pragmatism	Thinking in numbers rather than context, initial narrow focus, pragmatism, focus on small parts of a project, difficulty in seeing the bigger picture of a design project
Transport and Planning	Systems integrator	Not answered	Not answered
Transport, Infrastructure, and Logistics	Mentioned all 4	Analysing the given problem, determining the actual problem, finding solutions, connecting different parts together, innovation, solutions, broad knowledge, and integration-oriented	Being stuck in your own field/bubble, unable to rely on other fields/expertise, unable to see possible drastic solutions
Urban Water Management	Systems integrator	GIS knowledge, flexibility, systems design	Design of spatially detached systems, inflexible
Urbanism	Systems integrator Contextual engineer	Connecting different stakeholders, mediation, synthesising various streams of information to generate spatial designs, strategic planning, system thinker, holistic, grounded overview, fluid, flexible, organising, broad point of view, open, innovative, integrate systems, generalist to multiple topics and assess their part in the larger context, create overviews for everyone's understanding	Technical knowledge, weakness in quantitative methods, technology integration within space, unable to work within only one scale, might be at risk of being a generalist and hence not considered a specialist
Architecture	Systems integrator Contextual engineer	Problem framing and information synthesis	A lack of quantitatively defined goals with which to design and evaluate, broad and unclear 'value-based' aims
Building Technology	Specialist	Attention to detail, which invariably has a significant impact on the overall design	Lack of in-depth structural design knowledge
Landscape Architecture	Systems integrator	Generalist, knowledge of the different environmental and urban flows, integrating various solutions	Limited in spatial design, lack of technical knowledge, new technologies are coming out every day
Management in the Built Environment	Systems integrator	In interdisciplinary work, a manager is needed to bring everyone on the same page to achieve a common goal towards an integrated outcome	Not answered

TABLE 4 Summary of responses to the questions (19, 20, 21) on the role of an engineer

4.3 Survey results: Products of the projects

The six student groups collectively produced three scientific papers (Areso Rossia, 2020; Krishnan et al., 2019), seven group reports, one additional thesis, and 12 MSc graduation theses (Areso Rossi et al., 2018; Broere et al., 2019; Claassen et al., 2018; Dobbelsteen, 2018; Filipouskaya, 2019; Glasbergen, 2018; Höller & van de Wiel, 2019; Li et al., 2019; Möhring, 2018; Mujumdar, 2019; Mustaqim, 2018; Nederlof, 2019; Prida Guillén, 2019; Rao, 2019; Roubos, 2019; Salet, 2019; Vafa, 2018; Van den Berg et al., 2019; van Dijk, 2018; Van Driel, 2018; Van Klaveren et al., 2019; Yasaku, 2018, 2019).

The group reports either focused on the interdisciplinary process or the outcomes of the interdisciplinary design. Graduation projects delved deeper into disciplinary aspects while acknowledging that their work was informed by the mindset cultivated through engagement with other disciplines.

In response to question II-9, students were asked to evaluate whether they considered the final project an interdisciplinary design and how they assessed it. Engineering students, numbering 23, rated their projects with an average score of 7/10 (ranging from 4 to 10, with hydraulic engineers showing the most positive responses). Similarly, the 13 architecture students rated theirs at an average of 6.5/10 (ranging from 4 to 8). When asked to assess interdisciplinarity, the following criteria were mentioned:

- Presence of shared storytelling (interconnected ideas)
- Presence of interconnected solutions (serving multiple disciplinary objectives)
- Demonstration of the connection between problem-solving and problem-seeking, with a set of aspects presented in the final product
- Presentation of an integrated design and roadmap
- Demonstration of responsiveness to disciplinary boundaries, with active boundary-spanning evident in the analysis

These responses offer clear insights into achieving and evaluating interdisciplinary design. Among the most important features, students must develop a shared narrative of ideas that actively cross disciplinary boundaries and objectives in urban development.

5 Conclusions

This paper reflects on experiences with multidisciplinary student teams across six projects and presents insights gleaned from the questionnaire completed by the 38 participants (see Appendix A). It is important to consider that there is an imbalance in the numbers of students across different disciplinary groups. For example, hydraulic engineering and urbanism have larger cohorts and, therefore, may be more representative. However, this imbalance is mitigated to some extent by utilising broader classifications, such as civil engineering and architecture, rather than individual sub-disciplines.

Based on the survey results, the effectiveness of the Tohoku methodology is appreciated for three components: multidisciplinary team and interdisciplinary process, role of the engineer, and products of the projects. Regarding multidisciplinary teamwork and the interdisciplinary process, the survey indicates that the Tohoku methodology is experienced as successful because it facilitates not only conscious group building but is also explicitly linked to the interdisciplinarity aspects that are needed to bring together different disciplines (communication, scoping, fieldwork, and mentorship). On the role of the engineer, the survey indicates that students gain an understanding of their position during the project but tend to feel a little lost during the initial phase. From the results, a hierarchy can be recognised, where students in most disciplines consider themselves system integrators, engineering students consider themselves specialists, and architecture students identify as contextual engineers.

The evaluation of the final project results in respect to interdisciplinarity of the design was guided by several criteria, including interconnected ideas, solutions serving multiple disciplinary objectives, the connection between problem-solving and problem-seeking, and responsiveness to disciplinary boundaries, with active boundary-spanning evident in the analysis. These criteria provide valuable insights into achieving and assessing interdisciplinary design. The essence lies in fostering a shared narrative of ideas that effectively leverages disciplinary boundaries and objectives in the context of urban infrastructure development. By embracing these principles, interdisciplinary projects can yield innovative solutions that address complex challenges holistically and collaboratively.

The primary objective of this study was to assess the effectiveness of an interdisciplinary project for engineering and architecture students aimed at facilitating the integration of engineering principles into spatial design education and design principles into engineering education. Responses regarding 'satisfaction with the project' and 'usefulness for their career' suggest that experiences like these help bridge the gap resulting from the shift from practitioner-led to research-focused education. In contrast, architecture students expressed lower overall satisfaction with the project, and they may derive less benefit from its practical and interdisciplinary nature compared to their engineering counterparts. However, their challenge lies in how to effectively integrate and collaborate with representatives from various disciplines. Therefore, interdisciplinary projects, such as those investigated in this study, play a vital role in facilitating the integration of engineering principles into the spatial design process and design principles into the engineering process.

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