The Potential of the Technical University of Denmark in the Light of Sustainable Livable Cities

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Abstract: The Technical University of Denmark (DTU) has a long tradition for research and education in urban planning and sustainable urban development. An increasing societal focus on sustainability and urbanization in society supports this continuous focus on sustainable urban planning in technical educations. The focus on sustainable urban development includes understanding the role of civil engineering, water engineering, sustainable mobility and energy, and communities in developing future desirable solutions. However, beyond the challenges faced in each of the specific technical fields, there is a growing demand for integrated solutions. A proposal has been developed in the last couple of years to further develop DTU's education in urban development and livable cities with an emphasis on integration and interdependencies in urban engineering. This paper describes core professional design niches which by themselves have an impact on urban development, including water in cities, climate adaptation, mobility planning, building, energy, and community designs. A number of challenges in developing an integrated approach in the technical education are discussed in the paper. The increasing focus on sustainability but also on global urbanization, compact cities, and smart cities supports new thinking in urban planning and design in technical education. The paper suggests a new initiative to further develop the sustainable urban planning research and education at DTU.

Keywords: Sustainability, Livable Cities, Research, Design Education in Civil Engineering, Design Method.

Introduction

Societal challenges of the present are to a large extend contained within the field of urban design. The challenges are numerous and involve climate change and CO_2 reduction issues, which again are linked to health and social stability problem areas. There is a demand to manage this complexity in a systematic design process where very high levels of information concerning all levels are infused from the earliest of design phases.

The mission and strategy of DTU was to answer to this call for a higher information level in urban design processes, from politicians and others with responsibility of design of future urban developments (Technical University of Denmark 2013). An interdisciplinary task force of faculty from different departments was placed in charge of the work. This paper presents the mapping of the different technical scientific fora with relevancy in the urban scale. Important questions concerning interdisciplinary organization were investigated and the committee presented a first attempt on concluding on the specific yet generic question (Nielsen *et al.* 2012).

Task Force Results

Explorative and Consensus Seeking Meetings

Headed by an engineer with a management background and a facilitator, with a communication background, representatives from the main departments participated in a series of meetings initiated by the Deans of DTU. The head of the committee has been employed at DTU for a long period of time and has a background in urban planning (Hoffmann *et al.* 2004), and based on this knowledge she suggested representatives from DTU Environment, DTU Management Engineering, DTU Transport, and DTU Civil Engineering. To some extent this selection involves an undesirable narrowing of the disciplines involved, however a small core group was required in order to facilitate communication and the process. The meetings had a workshop character because the group made a clear decision from the beginning that the end result should have qualities of being operative and realistic ideas for the near future at DTU. The university had previously worked with mapping and outlining other interdisciplinary subject areas such as 'sustainability'. Technical scientific knowledge relevant for informing design processes on an urban scale is a much more narrow perspective. For example, it was relatively

clear to observe how much existing relevant research existed within DTU's existing structures.

In order to help define a space of solution the first meeting focused on a SWOT analysis (Strengths, Weaknesses; Opportunities and Threats). The SWOT should define the framework both viewed from within DTU and in a broader context of Society. See figure 1.

Internal view of DTU: strengths	Internal View: weaknesses
▪ DTU: Depth in Technical Scientific competences ▪ DTU Have design competences ▪ DTU: High ranked, research based University ▪	▪ Lack in priority given to coordination and integration of relevant specializations. ▪ No common understanding of and vision for the subject field. ▪ Low level of interdisciplinary culture and skills in the field. ▪ Low levels of holistic understanding in the urban field.
External view of DTU -Opportunities	**External View of DTU -Threats**
▪ A demand in society – exlicit from politicians for innovation, integrated solutions to many new challenges, new standards. ▪ A professionalization is in progress on the municipal level. ▪ Great potention for innvoation, govermal support and export.	▪ If Urban planning and design praxis is not based on a high level of knowledge, society risk making the wrong decisions (the post-factual society). ▪ Other academic institutions have strong brands in urban issues. ▪ Large scale international initiatives is currently redefining research and praxis of urban planning and design.

Figure 1. SWOT

The SWOT outlined that DTU's focus on technical scientific knowledge in urban scale issues could reserve a major role for the university because it is an exclusive role in the Danish context. At DTU there exists profound technical scientific knowledge within core urban issue areas. The other major Danish university stakeholders place their focus on social sciences or work within the Arts (design and architecture). However the profound technical scientific knowledge at DTU exists in its own right and the question of informing ongoing design processes with this knowledge has no or low priority. Failing to activate the knowledge present at DTU would pose a risk to society because investments in infrastructure, climate change issues, and new urban developments would not be based on the available knowledge, but only on knowledge at hand for the designers.

The Mapping of Existing DTU Research and Knowledge Areas with Urban Scale Relevancy

At DTU research environments in the departments are independent. In a number of these research environments, aspects of the research have a relevancy in the urban scale. The holistic design of cities as such is not explicitly a research area of any of the departments. Large amounts of knowledge that can be utilized in a design process are available. But some of the knowledge compounds of relevancy are actually just sidekicks to a central research area. In order to begin a more structured integration of this knowledge, a mapping of existing urban scale knowledge at DTU was made by the committee.

DTU Environment - Water and Waste Management

The Department of DTU Environment is experiencing a steep growth in interest concerning their research areas: water and waste management. Climate change, resulting in intensified rainfall and a raising sea level, places this department in the fore of what DTU can offer to future urban design processes.

Much water management research has focused on technical innovation with a range of new solutions developed to achieve a 'more sustainable and integrated urban water management cycle'. However Danish municipalities and utility companies are struggling to bring such solutions into practice. 'Green infrastructure', for example, requires the consideration of a larger range of aspects related to the urban context than the traditional urban water system optimization (Fratini *et al.* 2012).

Integrated urban water models should focus more on addressing the interplay between social/economical and biophysical/technical issues, while its encompassing software should become more user-friendly. Possible future directions include exploring uncertainties and broader participatory modelling. (Bech *et al.* 2014).

To achieve a successful and sustainable adaptation to climate change we need to transform the way we think about change.

DTU Transport

Transport is an important topic for cities across the world as accessibility and mobility are closely linked to urban development, competitiveness and wellbeing and therefore highly wanted. But other aspects of transport are also nuisances: congestion, risk, and reduced quality of life especially in urban areas where densities increase accessibility as well exposures to negative effects (Kristensen *et al*. 2014). Managing transport is therefore critical, but difficult as behavioral choices and responses plays a large role.

DTU's department of transport covers transport from the perspective of transport systems analysis, transport planning, transport optimization, and transport policy. Transport planning is conventionally supported by transport modelling as the main input to assessing and developing the transport system. Transport models developed by the department include spatially detailed in- and outputs partially supporting assessment of effects of future urban development patterns. However, more work is required to develop and exploit this capability in integrated urban and transport planning.

The emphasis in urban transport planning is becoming increasingly interdisciplinary with reference to multiple objectives such as congestion, environment and public health, as well as increasing intermingling of conventional transport planning (networks and fares) with urban design and management – including area renewal and actual 'leverage planning'. Examples include the current emphasis on cycling promotion (Nielsen *et al.* 2013), green transport plans, and high profile public transport infrastructure projects such as light rail and metro lines in Greater Copenhagen. In this widening agenda, the capacity for integration of transport with urban management, urban design, environmental planning – as well as IT and communication requires further emphasis.

DTU Civil Engineering

The design and construction of the buildings and infrastructure that make up the city as such is the topic of civil engineering. However, classic civil engineering is challenged in the present because traditional structures and systems are expected to be part of a larger whole. For instance the operation of buildings is traditionally the area of HVAC engineers. When legislation favors buildings that produce energy, the traditional operational system of a building becomes an integrated part of the energy grid. Another example of the new complexity is how research demonstrates that urban layout determines the later energy consumption of the buildings (Strømann-Andersen 2012).

In order to design low-energy buildings, the building industry has developed very good software that quickly and accurately can simulate daylight, sunlight and the effects on indoor-climate/energy-balance of a building. These tool are slowly been transferred to urban design in order to calculate the energy production potential of a structure and the local climate of an urban space in a planned development.

Taking inspiration from the building industry, urban planners and designers could study the development of highly informed design processes behind zero-energy buildings. In a developing process between engineers/architects and software developers, an array of simulation tools with good interfaces to 3D modelling software has been developed. These tools condense technical scientific knowledge and make it easier to integrate this knowledge in design processes in order to achieve documented levels of sustainability.

For example, computational fluid dynamics was used decades ago as a simulation tool for calculating flow in tubes, etc. but is now so fast and accurate that it can inform an ongoing design process about the flow of wind in a planned urban development.

DTU Management Engineering

DTU Management Engineering contributes actively to the development of decision-making tools, process optimization and an innovative, competitive and sustainable use of technology thereby addressing some of society's grand challenges including sustainable cities. The research especially focuses on the areas of energy and climate, production, cities, health, and food. The department is organized with its own administration and consists of five research divisions: Management Science, Quantitative Sustainability Assessment, Technology and Innovation Management, Systems Analysis and Production and Service Management - and two centers: UNEP Risø Centre and DTU Business.

Seeing real-life decision-making as deliberate choices between identified solutions on an identified problem, engineers often have the role of designing and evaluating the expected costs and benefits of these alternative solutions and to ensure decisions can be made on an informed basis. In the ideal world, all information is available, however the reflective practitioner has to operate and execute decisions in situations with inadequate knowledge. The tendency in management research founding is to set up interdisciplinary teams which can provide decisions makers with both qualitative and quantitative justified decisions. For municipalities, which have sustainable development as their core business (Galamba and Nielsen 2010), there are challenges with inherent dilemmas of increasing complexity and where simplifications includes both ethical and specialist insight (Hoffmann *et al.* 2004).

Mapping of DTU Courses Relevant for the Urban Scale

Research is not the only potential contributor to new urban design processes. Education also plays an important role in pushing the development towards a holistic and design-process-oriented approach. Educational programs can be a tool to make the desired development take place. However the realistic scenario would be to make a patchwork of existing courses and connect them into being a new context for DTU's urban focus.

The task force group made a mapping of university courses that could be stepping stones in the process of outlining applicable technical scientific knowledge to future urban design processes. A few of the courses were actual urban planning courses, but the majority was courses where a small part of the course program contained subjects of importance for an urban scale.

An overview of the courses is given in Appendix 1. Each course has a 5 digit identity code. Those without a course number (XXXXX) are suggested courses, which are currently not in the

official course catalogue. The courses are changing and the current version of the DTU courses database is available at www.dtu.dk.

The courses were divided into four categories. The first category consists of courses about technical scientific subjects where a small part has relevance for an urban scale: e.g. courses on building energy, daylight, computational fluid dynamics, wind, lighting, district heating, large scale structural design, soil engineering etc.

The second category consists of courses about urban management with content relevant for a design process: environmental management, integrated water resource management, transport economy, transportation models, risk assessment methods, Planning Theory, introduction to planning, knowledge based entrepreneurship, technology, economics, management and organization , strategy and planning methods, management of change, product development/ conceptualization, environmental economics, and innovation management.

The third category consists of courses with a major part that is relevant for urban design: water supply, sewage systems, waste management and traffic planning.

The fourth category involves design projects and courses on interdisciplinary design methods.

Based on this mapping the committee outlined a new 2 year MSc. Program made from existing courses supplemented by interdisciplinary design projects.

Mapping of Existing Interdisciplinary Cultures within DTU

Research in design methods that can integrate technical scientific knowledge in design processes is taking place in different research environments at DTU but an explicit focus on Urban Planning and Design is not a research area. Interdisciplinary design methods are dealt with on the same level. This ability to assist society in making the informed decisions demands the development of an interdisciplinary approach within the university. It also requires that the high ranked research environments should invest time in making their knowledge accessible to non-engineers in order to make this knowledge operational in a design process.

DTU Management Engineering & Interdisciplinarity

DTU Management Engineering has the role of providing generic research and education that transcends the knowledge ‘silos’ of DTU across the departments. “Cities” is one of the focal areas within the department and can be characterized by three different main approaches with roots in different research groups’ tradition: system analysis at local and societal level; products and service systems (e.g. Quantitative Sustainability Assessment); and the stakeholder perspectives e.g. of a facility owner (PSM). Courses are offered as part of the education on Design and Innovation; the education on Planning, Innovation and Management; and as generic courses which feed into all of DTU’s educations.

DTU Civil Engineering & Interdisciplinarity

UN statistics demonstrated a decade ago that 40% of the energy consumption used in society was for operating buildings. In order to reduce this, highly informed design processes were developed. ‘Integrated Design’ and ‘Integrated Energy Design’ are design methods developed in close collaboration with engineers, software developers and architects. The basic point made is that the major part of a buildings’ energy consumption is determined in the early design decisions (often made by architects). An effort was made to develop software that could simulate indoor climate and energy consumption in the early design phases and was easy to use by a multidisciplinary design team. The lessons from this period were brought into the field of BIM (building information modelling). BIM was a decade ago mainly about having a 3D digital model of a building or infrastructure project that would enable a more efficient detailing and construction phase. Learning from Integrated Energy Design, simple 3D models are now produced in the early design phases and imported and exported in different simulations software, thus gradually informing the design more and more until the final 3D model is used for construction. 3D models and simulation software with good interfaces to the 3D modelling ‘drawing’ programs enable a much closer interdisciplinary work process.

DTU Environment & Interdisciplinarity

The Department of Environmental Engineering ceased to teach any drawing or 3D modelling skills to students and faculty a decade ago. This constitutes an important obstacle in integrating the technical scientific knowledge of the department in the urban design process. Concerning simulations tools, several GIS based tools exist. However they can only depict existing situations and have no interface with common CAD software. In a simulation tool like Mikeflood, new designs can be investigated but all new systems must be designed within the software and no drawings can be exported or imported. Mikeflood is time consuming and thus risks being bypassed in the design process.

DTU Transport & Interdisciplinarity

DTU Transport has a strong position in transport modelling, transport planning, and policy – all topics which are obviously linked to urban planning and multiple other policy areas. Importantly, however, the department has gravitated towards national or large scale issues as well as towards project appraisal. Developing projects/proposals is more weakly positioned in the curriculum and this may make it more difficult to engage in interdisciplinary design. Additionally transport systems issues are often approached at a scale somewhat above a 'usual' design scale (zones) which may also be an obstacle for interdisciplinarity. But as new urban brown field developments like 'Nordhavnen' involve travel behavior objectives, and transport outcomes are affected by urban form, interdisciplinarity should be developed. Simulation tools like Vissim provide a link to the design scale (interface to CAD) and can simulate the flow of cars, bicycles and people as part of a traffic impact assessment. However, they require supplementary evidence/tools depending upon which outcomes are in focus (CO_2, congestion, public health, etc.). Important issues may involve bridging between spatial scales as well as between cultures. Transport planning may be said to be less visual and less confident in its ability to determine the outcome of a specific project compared to e.g. urban design in general.

DTU Educational Programs & Interdisciplinarity

Concerning education, DTU Architectural Engineering and DTU Design & Innovation are study lines focused on the interdisciplinary integration of engineering knowledge in the design processes. DTU Design and Innovation has a bias towards social sciences and small scale products where DTU Architectural Engineering tends towards architectural design and the built environment.

DTU External Partners & Interdisciplinarity

In general, there are strong links between specific DTU departments and external partners concerning interdisciplinarity. Collaboration with industry is common at the course level and is a prerequsist in most, larger research applications where it is common to involve several DTU institutes and external partners.

Apart from the ad hoc environment of specific research projects, the integration of technical scientific knowledge from many different departments into the design processes is the core interest at several "close to practice" initiatives e.g. DTU IPU; Scion DTU; Climatekick, DANVA; ATV to mention a few major players. At DTU Environment there are close links to the Landscape Design Department of the University of Copenhagen.

At DTU Architectural Engineering there are permanent collaborations with the Royal Academy of Fine Arts, School of Architecture and Design concerning research and mutual courses.

Outline of Institutional Features to Enhance the Development Further – The Synthesis

DTU has platforms in IPU, DTU Management Engineering, Design and Innovation, and Architectural Engineering for interdisciplinary design processes. However the interdisciplinarity is not systematically organized and as employees at DTU we experience both visions of integration but also physical, organizational, administrative and economic barriers for further interdisciplinary collaboration.

There seems to be a deficit in the integration between knowledge silos within DTU's departments. DTU departments have separately developed interdisciplinary collaborations with external partners within the urban design field. However this is not coordinated and exposed internally at DTU.

A release of the DTU potential would demand that DTU would be willing to place more interest in design processes, because this is where project decisions are made. DTU is a technical university where focus has always been the actual making of 'things', which should make it possible to bridge the internal 'knowledge silos' and bridge from research out to the ongoing urban design processes. However, the kind of development needed in order to meet the expectations from politicians and society, would demand a huge effort and focus at a strategic level on interdisciplinary urban design process.

Discussion

The initial driving force for the work was the SWOT analysis. It showed the potential of combining different technical scientific disciplines in an interdisciplinary design process together with architects. The potential risk of society making poor investments if the designs are not based on high levels of knowledge also stood out. However the design of cities is so all-encompassing a subject that university leaders and others are challenged by how to set the boundaries and thus settle the funding. In this way 'urban design' is linked to the term 'sustainability' in the sense that it is too large and all-inclusive. However the same was said a decade ago about sustainable buildings and by limiting the focus to indoor climate and energy consumption a major step was taken. In the same sense, a higher information level in the design processes behind urban development could also be achieved by focusing on the tools and methods at hand in narrow areas, and combining those.

DTU is doing exactly as described above by establishing a Water Technology Center hosted by

DTU Environment (starting this year) and a Climate Center next year. They represent looser networks around a dominating single discipline that is not specifically urban design focused. Interdisciplinary design and highly informed modern design methods can develop from this. They have, as a foundation, the same integration between departments.

As with buildings, it is in the early design decisions that will have the largest effect on a city's later performance. The classic dilemma is that researchers are identity challenged, when they are asked to simplify their knowledge into something so fast moving that it can inform an ongoing multidisciplinary design process in the early phases of the process.

Conclusions

The conclusion of the group was to recommend a Centre that should do 3 things:

- Maintain and host a high level of research in interdisciplinary design processes
- Coordinate DTU knowledge and research with relevance at the urban level, and host large interdisciplinary urban scale research projects
- and last but not least, coordinate and host a M.Sc. program in Livable Cities, where the combination of deep technical scientific knowledge and the application of this in design projects should be the topic.

The committee presented the idea for a center of livable cities in December 2013. Unfortunately, DTU could not accommodate the suggestion at that time.

The mapping shows that DTU has a large amount of research and education relevant for urban design. However the efforts are not coordinated and the research is not exposed and communicated to the other departments and the outside world as important to urban design process. Other characteristics include the fact that several of the 'silos' at DTU lack design skills and tools and that while interdisciplinary fora exist at DTU, the work is not focused on urban design.

While a Centre has not been realized as suggested, other initiatives are indicating that DTU is developing to meet the societal challenges also in urban planning, but still from a mono-disciplinary approach.

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Appendix 1

Vision	Engineering Smart Sustainable Livable Cities Conceive, Design, Implement, Operate (CDIO)					
Themes	Transportation and mobility	Building design	Water management	Space and GIS	Facilities management	Climate adaptation
Courses: single theme	13106 GIS and road traffic planning for MSc students 13133 Introduction to transport models 13150 Transport economics 13232 Transport safety 13233 Decision support and risk analysis 13236 Sustainable transport assessment 13428 Urban planning and transport planning 13450 Intelligent transport systems (ITS) - modelling and analysis 13531 Transport logistics and optimisation	11115 Building energy and technical services- integrated design 11116: Sustainable buildings 11127 - Sustainable heating and cooling of buildings 11142 Daylight and lighting 11374 Seismic and wind engineering 11994 Engineering in urban design 11997 Sustainability and life cycle assessment 11420 - Engineering in mountains - soil, rock and nature 11375 - Bridge structures 11129 - Sustainable district heating 11222 - Indoor climate 11465 - Advanced geotechnical engineering	12233 Water pollution 12236 Environmental and human health risk assessment of chemicals 12333 Water resource management 12335 Ground water resources 12500 Energy resources 12242 Environmental management and ethics	30090 Design of digital systems, 30510 GPS, GIS and setting out 30532 - Introduction to digital mapping and GIS	42259 Facilities management XXXXX Sustainability in FM XXXX Real estate strategies XXXX Maintenance and operation of buildings and infrastructures	42262 Climate models, observations of the past and the present and climate changes projections including sea level rise 30730 - Space weather forecast and effects
Courses: urban planning	42279 Interdisciplinary urban planning course of Danish universities (LFB) 42280 Smart, connected and livable cities 42273 Urban planning and sustainable urban development 13235 Planning theory					
Other relevant courses	42246 Project management 42XXX Innovation management 42631 Environmental economics 42628 Product development/ conceptualization 42543 Management of change 42532 Strategy and planning methods 42490 Technology, economics, management and organisation (TEMO) 42435 Knowledge based entrepreneurship 42401 Introduction to planning 42084 Work system design 46200 Planning and development of wind farms 41083 Technology platforms and architectures 41272 Risk and decision-making 42171 System safety and reliability engineering					