



Report

NSF Sustainable Urban Systems (SUS) Conference

Graduate Education for a New Sustainable Urban Systems Science: Designing a New PhD Curriculum Integrating Sustainability Science and Urban Science

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¹ The report reflects the discussions held during the conference and the perspectives, opinions and experiences of the conference participants (listed in the agenda included as an appendix). The report was written by those listed as “preparers”.

I. Introduction

This is a report on the discussions held during an NSF SUS conference “Graduate Education for a New Sustainable Urban Systems Science: Designing a New PhD Curriculum Integrating Sustainability Science and Urban Science”. The conference was motivated by the call made by the NSF for “...developing the next generation of sustainable urban systems science.” (NSF 2018) The conference was premised on the assumption that such continued development will require the training of new generations of urban sustainability scientists, and that both the content and manner of training will be different from those established degree programs.

The assembled group of participants represented a variety of disciplines and academic fields—urban economics, economic geography, regional science, urban sociology, archaeology, anthropology, urban planning, political science, architecture, design, sustainability science, urban ecology, computer science, engineering and physics—as well as different manners of engaging with teaching, research and policy-making. The conference’s discussions were greatly enriched by participants knowledge of urbanization in the USA, Canada and Mexico, Western Europe, China, India, Africa, Guyana and South America. The discussions were held in a frank, respectful and constructive manner. While strong opinions were voiced, dogmatic stances were avoided and “epistemic humility” was prevalent.

For a long time, the study of different aspects of urban areas was pursued by different disciplines. For example, the time-depth of human settlements was the realm of archaeologists and historians, the spatial organization and socioeconomic statistics of urban systems were left to geographers, demographers and regional scientists; the economic productivity of cities to urban economists; the infrastructural systems of cities to civil engineers; and land uses to city planners. Sociologists have historically studied neighborhoods, race and segregation, and sometimes crime, while social psychologists have been concerned with social behavior as embedded in urban environments. The realization that urban areas as social and physical entities are now among the main drivers of ecological and environmental changes has led to the surge in urban ecological research during the past few decades. These perspectives do connect of course, but they have rarely constrained each other or been integrated in the service of building a consistent and common body of knowledge about urban areas and urbanization.

Another dimension of this diversity deals with the study of urban systems from around the world and across time. While early in the study of cities in the 19th and 20th centuries empirical data was overwhelmingly more available for large cities in Europe and North America, today this picture is very different allowing us increasingly to study settlements of all different sizes, all around the world in quantitative comparative ways. Similarly, the digitization of archeological and historical data, together with new survey methods, such as those facilitated by radar and high resolution remote sensing are providing access to new data on many cities and settlement systems throughout time and in the present. Technological and social developments have combined (intentionally but also as unintended consequences) to generate unprecedented amounts of data (e.g., through cell phone data and social media) concerning what people (individuals and organizations) do when they agglomerate in cities.

The comparative analytical and empirical possibilities for understanding urban systems and urbanization demand the unification of theoretical frameworks developed for certain places and times. “Urban science” is on the cusp of becoming a well-defined field that is examining a shared set of phenomena across many disciplines, while developing common theoretical ideas, underlying principles and analytical methods for integrating knowledge on urban areas across the globe and across history.

We believe it is useful to distinguish urban science from “urban studies” in this context. Whereas urban studies has for several decades pursued the multidisciplinary study of cities, but from a primarily social scientific perspective and through case studies, we view urban science as an emerging field that integrates the historically social scientific focus of urban studies with research on cities from natural and physical science disciplines, to understand the drivers of urbanization, the relationships between urban systems, and the urban processes shared across settlements, as well as their variations. Urban science is emerging alongside the growth of related integrated disciplines. For example, urban ecology is integrating natural and social sciences to assess how urban areas alter local environments and drive regional ecological change (Grimm et al. 2000; Wu 2014; McPhearson et al. 2016). Sustainability science is starting to address the challenges and opportunities posed by sustainable socioeconomic development and adaptation to climate change in the setting where most human beings now live, namely urban areas.

Yet much still remains the same since the NSF sponsored a workshop in 1998 on urban sustainability:

“Yet geographers (and others), dissuaded in part by the political cacophony surrounding the debate, have largely neglected the challenge of conceptualizing the interrelationships among social, economic, political, and environmental processes, a challenge simultaneously posed by the scale of predicted urbanization and by the idea of sustainability. Existing structures of knowledge creation and compartmentalization in academia exacerbate this silence. Scholars of urban processes affecting first-world cities rarely interact with scholars of third-world cities. Theories of third-world urban processes rarely inform current theorizing about first-world cities. Neither group has a strong tradition of embracing environmental or ecological concerns. Urban scholars investigating global–local linkages focus primarily within the economic sphere and neglect environmental impacts and questions of ecological sustainability. Scholars focusing on environmental processes (including researchers examining global environmental change and political ecologists) have almost completely disregarded the urban. The barriers separating these distinct areas of research—first- and third world urban processes and environmental processes—have grown to be sturdy and quite impermeable.” (Hanson and Lake 2000, pp. 1-2)

No doubt we must continue hammering away at the barriers and advocating for change within established disciplines—but designing a curriculum to be explicitly transdisciplinary is *now* an urgent intellectual task. (Here we adopt the convention whereby transdisciplinary research crosses disciplinary boundaries and integrates distinct domains of knowledge, to generate novel insights, in a manner that goes beyond bringing together or combining existing units of knowledge.)

Cities present both the problems and solutions to sustainability challenges of an increasingly urbanized world. Our species' success in addressing the related challenges of adaptation to climate change, sustainability, poverty alleviation and shared prosperity will be largely determined by what happens in urban areas. If we are to effectively manage this process and realize the potential of our increasingly urban planet, we must develop a better and deeper understanding of the drivers of urbanization and the way cities function as emergent socio-spatial phenomena. We need more and better urban sustainability science, and to get it we need more scientists trained to generate such scientific output and to do so in a manner that informs citizen action.

This report is not a detailed outline of what PhD-level training in sustainable urban systems science (SUS-science) should consist of—a two day discussion, even one as intense, focused and well-informed as the one which occurred at the conference held at Arizona State University, is not enough sufficient to craft such a curriculum. This report ought instead to be read as *initial design notes* for developing a doctoral program on SUS-science.

The report is organized as follows. The next section presents the main themes (or perspectives or propositions) that ground our suggestions regarding curricular content and pedagogical approach. Curriculum content and pedagogical approaches are the subject of section three. The fourth section presents some salient questions as examples of the type of inquiry that a multidisciplinary and integrative training in urban sustainability should pose and address (at the risk of them becoming explanatorily orphaned). The ways in which rigorous training in urban sustainability can be the basis for working in policy-making or with community organizations striving to change urban reality is discussed in section five. Section six concludes with some remarks about how to continue, deepen and widen the discussion on designing new academic training in urban sustainability. The appendixes include the conference's agenda (with the list of participants), questions to consider when proposing a new PD program within an University, and specific suggestions for curriculum content are presented as appendixes.

II. Foundational Themes

“The urban environment that humans are so busily creating is many things: a biological environment, a social environment, a built environment, a market environment, a business environment, and a political environment. It includes not only the versions of these environments that exist inside a single city, but also those that are emerging from the interaction between cities. Our understanding of the urban environment will draw on existing academic disciplines, but it will also develop its own abstractions and insights.”
(Romer 2013)

1. Training in sustainable urban systems (SUS) science or urban sustainability science is premised on the scientific and pedagogical implications of the view expressed in the above quote from Paul Romer. The related notions that the city is its own unit of analysis, and that urbanization has been and continues to be a truly multifaceted and “complex” process are to be taken seriously, as are their training and pedagogical implications.
2. *SUS is a new field with its own unique fundamental research questions.* Training in SUS-science is not conceived as replacing training in urban archaeology, urban sociology, urban

planning, urban economics, economic geography, urban ecology, regional science, metropolitan informatics, transportation engineering and ethnography (to list just a few of the existing urban-focused research domains). For many research questions and policy problems specialized training in these well-established disciplines will be required and appropriate. Instead, graduate training in urban sustainability science should facilitate research which complements and integrates discipline-grounded research.

3. *A SUS researcher will be inherently transdisciplinary.* A graduate in urban sustainability science ought to have an epistemological and research attitude leaning towards integration. Some might derisively dismiss someone trained in SUS-science as a “Jack or Jacqueline-of-all-trades and master of none”. We prefer to think of such individuals as “integrators” capable (intellectually and temperamentally) of weaving different strands of accumulated insights into novel research and practices, and to pose questions which transcend academic boundaries. However, SUS PhD students may declare an emphasis in a standard urban-focused domain, which may provide a basis from which to integrate that particular focus into the overall SUS framework, especially for the purpose of scoping a dissertation.
4. *Urban science will play a central role in advancing sustainability science.* The website of the *Proceedings of the National Academy of Sciences of the United States of America* describes *sustainability science* as “. . .an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet’s life support systems.” Nowhere are these interactions more intense, stark, concentrated and consequential than in urban areas.
5. *History matters.* The surest argument as to it being possible for the future to be different than the present is that the present is different from the past. Current urban conditions have grown out of the near and historical past. A historical perspective greatly helps to understand how deeply rooted practices and processes which need to be change are, and therefore how difficult it can be to change them. Despite historical contingency and path dependence, the recognition of similar empirical regularities in both contemporary and ancient contexts can help in identifying fundamental ingredients of urban life in ancient and modern contexts.
6. *Urban ecology matters.* Urban ecologists seek an understanding of how urban settings shape the socioecological interactions within them, and their role as both drivers and responders to environmental change. If cities are to adapt to climate change, the ecological features of urban life need to be incorporated into scientific explanations of how cities function.
7. *Science matters.* *Sustainable Urban Systems Science* does not equal, nor is it even closely related, to the domain of practice and academic training which goes by the monikers “urban analytics”, “metropolitan informatics” or “smart cities.” SUS-science takes the “science” in the name seriously: it is dedicated to seeking generalizable empirics, insights with far temporal and geographic reach, and fundamental knowledge about how urban systems function and how this functioning can be positively and sustainably altered. Our understanding of how cities function as engines of development, of the drivers of urbanization, and of the social, economic and physical factors that shape urban areas all need to improve (analytically and empirically)

for effective policy-making to occur. In short, more and better science is needed for urbanization to become a vehicle for shared prosperity (Glaeser and Joshi-Ghani).

8. *People matter.* Academic training in urban sustainability must put the “social”—the myriad of interactions that individuals engage in when they live and work in cities—up front and in the center. How do urban environments (social, physical, cultural) facilitate and constrain human interactions? What is possible when humans agglomerate? Human social life embedded in social networks in urban physical spaces is an essential component of urban sustainability science.
9. *Not everyone will become a professor.* It is anticipated that not everyone who receives advanced training in urban sustainability science will aspire to become a professor or academic researcher; some urban sustainability scientists will work in national laboratories, in think-tanks, in policy-making or work with communities trying to affect change. It will therefore be important to develop both academic tracks for researchers and for those students intending to become practitioners. For the practitioner track, the ability to engage with a variety of stakeholders, to participate in community data collection efforts, and to formulate research questions in response to what residents of neighborhoods think is important to understand will be important skills to cultivate.
10. *Content, pedagogical practice, and research culture must all be reworked.* Developing new graduate education in urban sustainability science is not simply a matter of developing new content. How the content is taught—how pedagogy instantiates and reinforces a style of inquiry, a culture of transdisciplinary science and an appreciation for co-production of knowledge—needs to be considered an integral part of the novelty of urban sustainability science.
11. *Is a new PhD needed?* Although we agree that new graduate (and even undergraduate) training is needed, the administrative vehicle used to convey this training needs to be carefully, and creatively, considered. We are well aware of the administrative and financial burdens faced when forming a new graduate program, and it could be that important aspects of urban sustainability science can be articulated and advanced by modifying and augmenting existing graduate programs, including for example existing graduate programs in urban studies and sustainability science.

III. Curriculum Content and Pedagogy

A. Urban Science and Urban Sustainability

The following are epistemological, empirical and scientific stances that should guide the construction of specific curricula in sustainable urban systems science. (Appendix 2 presents examples of proto-curricula developed by sub-groups of conference participants.)

1. Many insights into the origins, development and functioning of cities, and on the role of cities in socioeconomic development, have been accumulated under the aegis of *urban economics*, *economic geography*, *regional science*, *urban planning*, *urban sociology*, *civil engineering*,

transportation engineering, archaeology, and anthropology. There have been rich *histories* of individual cities and urban systems which highlight what is distinctive and contingent and also help to identify what is common and enduring. A program of study in urban sustainability needs to build upon all these insights, respecting their disciplinary origins, bringing them into dialogue and explicitly identify foundational commonalities. *Deliberately bringing together existing insights, combining well-established methods, and integrating explanatory perspectives can generate novelty.*

2. We note that the disciplines that study cities and urbanization nowadays share much methodology, data, and findings. (Shared methods include network models, GIS, statistics and information theory, population dynamics, dynamical systems, scaling analysis and econometric analysis).
3. There have been articulate calls for the development of an “urban science”—see, for example, Acuto et al. (2018a,b), Alberti (2017), Batty (2018), Bettencourt and West (2010), Haila (2008), Kotokosta (2018), Ramaswami et al. (2012), Solecki et al. (2013), Vandecasteele et al. (2019). There have been equally articulate calls for the development of urban sustainability science (Grimm et al. 2008, Pataki 2015, McDonnell and MacGregor-Fors 2016, National Academies 2016, Waldrop 2019). Urban sustainability students need to be conversant with these calls and understand their underlying arguments. But at the same time we argue that these calls have not adequately highlighted the role of theory in the development and use of urban science, nor have they described in sufficient detail what type of transdisciplinary integration is needed for urban sustainability science to be “more than the sum of its disciplinary parts”.
4. Interdisciplinary approaches are now widely appreciated as necessary to integrate and cross-validate hypotheses.
5. There is a growing recognition that various components and scales of urbanism are complex, interconnected, and exceed the explanatory abilities of any single discipline.
6. Theory is important. But what do we mean by “theory”? To paraphrase Ostrom (2009), “without a common framework to organize findings, isolated knowledge does not accumulate”. And echoing Darwin: “Let theory guide your observations.” For us, theory provides testable and falsifiable general explanations of observable phenomena. It proposes which processes and properties are central in producing such phenomena and which are ancillary. It does not seek to explain everything, but to reveal fundamental commonalities, based on observable properties and proposed processes.
7. Empirics matter. Cities around the world and throughout history vary tremendously in their sizes, forms, and their economic and political contexts. Nevertheless, there are coarse-grained empirical regularities that are well documented by observations and data. Empirical commonalities include: neighborhood organization, social inequality, non-linear agglomeration effects, interdependence reflected in a division of knowledge and labor, regularities in the relative distribution of city sizes and other “laws of geography” (e.g., gravity-Tobler models, Gibrat’s Law, Zipf’s Law), and the role of urban areas as the privileged setting for invention and innovation (scientific, technological, economic, cultural, artistic, political).

A growing body of comparative urban studies highlights fundamental similarities and ephemeral differences. Embracing the empirical richness of urban studies should be a hallmark of urban sustainability science training.

8. Data! We have data! Two data generating phenomena are currently affecting the study of cities which are paradoxically incongruent. On the one hand we have a greater abundance and a variety of data than we had even 10 years ago: remote sensing (satellite) data, open street data, detailed maps, data on individual-level behavior, micro-level socioeconomic data, etc. On the other hand, the very spatial definition of a city (or metropolitan area) has become problematic and contested: how can we delineate the physical boundaries of a space of social interactions? Where do cities' areas of influence (social, economic, ecological) begin and end? Students of SUS-science must be able to use the varied data on cities while being aware of the non-trivial choices made when spatially identifying cities.
9. A student in urban sustainability science ought to be comfortable travelling across disciplinary boundaries and using conceptual language that connects disciplines. SUS students, scholars and practitioners should actively promote deeper dialogue between researchers who study urban systems across different eras, scales, and disciplines, aiming at a synthesis of communalities while recognizing contextual factors.
10. A commitment to open science is needed, especially with regard to the sharing of urban data (as a counterweight to the commoditization of urban data).
11. Foundational view of cities (throughout time): as social networks embedded in physical infrastructures and natural environments that convey natural resources, goods, energy and information over large distances for use by people in cities. The sustainability and adaptability of cities and urban systems therefore depends upon the *complex and cross-scale interactions* between the social networks, the natural systems, and the engineered infrastructures, and the institutions devised by humans to manage all these systems.

B. Pedagogy

The formation of a new generation of urbanists comfortable crossing disciplinary boundaries, well versed in the language of different research traditions, familiar with different ways of understanding urban phenomena and committed to the integration of urban science and sustainability science requires new approaches to teaching and learning. Being able to coordinate different styles of inquiry, ability to successfully work in teams, stakeholder engagement, listening intently to different points of views, these are all necessary skills, not simply marginal additions to the usual analytical and methodological competencies. To achieve the above goals, transdisciplinary teaching approaches are required, which explore each and every urban issue holistically from multiple disciplinary perspectives and through multiple pedagogic models (e.g., lecturing, student-led discussions, and interactions with stakeholders) and teaching-assistant technologies (e.g., course management tools, presentation software, and online collaboration tools). Many courses may be best team-taught, which would require instructors from different fields work together with themselves and with students.

We note that graduate training today must not only prepare students for careers other than tenure-track faculty, it must also make them “future proof”.² Today’s students (graduate and undergraduate) must be prepared for jobs that don’t exist yet, but also for jobs that exist now but will look drastically different in the future. Knowing how to learn, complex problem solving, critical thinking, creativity and the ability to see connections among seemingly distinct analytical perspectives are crucial skills for a SUS graduate to remain useful as developments in technology, governance, and social organization affect how cities are studied, managed and designed. These considerations must deeply affect how teaching and training are conducted in a SUS graduate program.

IV. Questions animating a graduate program in sustainable urban systems science.

Students in a program on Sustainable Urban Systems Science should be conversant with the questions traditionally posed by the many disciplines which study cities but should pose different questions and seek different types of answers.³ These are some examples of questions that should permeate the teaching of and the research by a new generation of SUS scientists.

1. What is an urban area? *What* (and for *whom*) is it for?
2. Why has urbanization been such an inexorable process in history?
3. What are the limits to urbanization? Will future megacities be very different from cities heretofore?
4. How should urban sustainability be defined? On what spatial and temporal scales can urban sustainability be most effectively studied and enhanced?
5. What aspects of modern cities promote human well-being, and which hinder it?
6. What would sustainable urbanization look like? In what ways will it be different from previous and existing urbanization episodes?
7. What has been the role of poor and informal neighborhoods (“slums”) in urban socioeconomic development throughout urban history? What makes some slums conduits for their residents’ socioeconomic improvement while turning others into “poverty traps”?
8. Why is urban poverty and racial/ethnic segregation so hard to eliminate?
9. How can the experiences of individuals known through ethnographic and other forms of field research be linked to quantitative, big-data research?
10. How do the social networks among city dwellers, the economic networks between city-based firms, and the transportation networks between cities and regions intersect and interact to animate cities?
11. What aspects of urban metabolism are technology-specific, and which are fundamental to urban agglomerations?

² www.kauffman.org/currents/2019/09/rethinking-education-to-make-graduates-and-workers-futureproof?utm_source=newsletter&utm_medium=email&utm_campaign=E_Scholar_9_27_2019.

³ The answers should be evidence-based and scientific but result from a greater methodological diversity and seek to integrate existing insights rather than contribute to the existing repertoire of minutiae.

12. Will “digitalization”, the continued decrease in transport costs, “virtual reality” and AI all diminish the benefits of spatial agglomeration? Will these technologies facilitate achieving urban sustainability?
13. What is the relationship between the form and function of cities?
14. Can urbanization decarbonize and still sustain socioeconomic development?
15. What is the future of small towns and medium cities especially in the developing world?
16. How is urbanization changing our idea of ‘being human’? (Homo Urbanix?)
17. Why are the above questions so difficult to answer?

V. Beyond Academia

Several technological and market transitions are occurring alongside urbanization that present an opportunity for elevating human development and improving both human and ecological well-being (e.g. autonomous vehicles, renewable and distributed energy systems, the shared economy). The impact of these technological advancements will need to be studied across cities, in different regional contexts, and their impacts on environmental, social, economic, and infrastructural systems will need to be understood. Currently, we lack both the science and the scientific infrastructure to inform how these innovations may alter pathways of urban resource consumption, wealth distribution, and urban quality of life. Training in SUS could contribute to these questions, and other research efforts that require analysis that transcends single cities, single sectors, and singular impacts. SUS graduates that find employment in the private sector will be equipped with a broader understanding of technology’s ripple effect on urban systems, enabling industries to consider, and avoid, unintended consequences.

Recent developments in the generation, acquisition and curation of different types of urban data, combined with increases in computational power (including remote-sensing, mobility, social media and community-collected data), improvements in computational processes (e.g., machine learning, AI, pattern recognition, spatial statistics, geographic information systems, network models) have greatly transformed what urban planning/management can do. Degree programs such as NYU’s Center for Urban Science + Progress’ Master of Science in Applied Urban Science & Informatics, the master’s degree on Smart Cities and Urban Analytics offered by Centre for Advanced Spatial Analysis of the University College London, or the Urban Tech masters’ program recently launched by the Jacobs Technion-Cornell Institute at Cornell Tech address the training needs and potential of big data + urban analytics. Individuals receiving this type of training will be able to work with stakeholders in the private, non-profit and governmental sectors to advance the practice of evidence and analytics-based urban management.

As already noted, doctoral-level training in sustainable urban system science will lean towards fundamental science, thereby deepening the theoretical and empirical underpinnings of how we understand urbanization and sustainable development. As such, a PhD in SUS-science is not simply an extension (nor is it a substitute) for the type of master’s programs in urban analytics referred to previously. Furthermore, “co-production of knowledge” in collaboration with actors other than academics, and engagement with diverse stakeholders in the formulation of research questions, are to be salient characteristics of graduate-level training in SUS-science. SUS scientists would combine their interdisciplinary theoretical grounding with sound transdisciplinary methods and practice, taking the co-production of knowledge seriously. Transdisciplinary co-produced

research emphasizes inclusiveness and iterative, deliberate negotiation as the mechanism for building shared understandings as a precondition for making progress jointly (Simon et al. 2018). Co-production of knowledge for urban areas is an imperative and requires the mutual and systematic appreciation and inclusion of knowledge aggregated by organized communities, NGOs, citizen science and other urban actors into a science of the urban. The experiences that have already been accumulated in the co-production of knowledge about cities needs to be thoroughly integrated into the training of future generation of SUS scientists.

We note the suggestions for enhancing the research process in urban sustainability made in another NSF SUS workshop—“Practitioner Led Urban Sustainability” (July 7-8, 2019)—and in particular echo that in a process of co-production, researcher and practitioner engage, as equals, in the identification of research questions and in the design, execution, implementation, and monitoring of research efforts. Those who have received PhD-level training in SUS-science should be able to work with the different NGOs, international institutions, and municipal governments which are actively trying to shape the management of cities towards sustainable and inclusive development be it through data collection, community participation in urban planning, policy-recommendations, and urban research and capacity development. Examples of these include the Sustainability Offices throughout city governments in the USA, Shack/Slum Dwellers International⁴, UN Habitat⁵, UN Global Pulse⁶, World Bank Urbanization Reviews⁷, and Cities Alliance⁸.

National laboratories (in the United States) and other governmental agencies seek to develop new basic science that will lead to tools and approaches that inform policies and plans for ensuring the security and resilience of national critical infrastructure and natural resources. It is of current interest to develop frameworks that capture dynamic multi-scale interactions among climate, energy, water, land, socioeconomics, critical infrastructure, and other sectors, and show how those interactions affect and are affected by urban systems. To understand how such frameworks can ideally be built requires both small and large focus, and a working knowledge of the content of the foundational themes articulated in Section II above.

VI. Building a Community for Curriculum Development

Building a new curriculum on Sustainable Urban Systems science, whether by revising existing academic programs or building a new PhD program, is of course a task extending well beyond a two-day conference. The conference participants are committed to continuing the discussion in order to build a fully specified curriculum. We are also committed to fostering discussions within our institutions and University departments and across the academic fields which we are part of. We intend to share the initial set of notes (summarized in this report) with the wider academic communities of urban science and urban sustainability in order to elicit comments, suggestions and even fierce criticisms. We as a group would like to meet again and continue working on a

⁴ <http://knowyourcity.info/>

⁵ <https://new.unhabitat.org/>

⁶ <https://www.unglobalpulse.org/>

⁷ <https://www.worldbank.org/en/topic/urbandevelopment/publication/urbanization-reviews>

⁸ <https://www.citiesalliance.org/>

SUS-science graduate-level curricula. We welcome suggestions by and assistance from the NSF as to how to disseminate this report.

As with other academic and scientific fields, NSF support for research activities and graduate education would greatly help in the further development and consolidation of a field of Sustainable Urban Systems science. Such support can be channeled through a dedicated program about SUS or through the many existing programs whose fields and domains overlap with urban sustainability. At the risk of being too fanciful, we conclude with a comparison to an existing NSF effort. “Navigating the New Arctic” is one of the NSF's 10 Big Ideas and embodies the Foundation's forward-looking response to the profound challenges associated with the Arctic. We argue that global urbanization poses equally profound challenges, and opportunities, for achieving sustainable development and adapting to climate change. Many scientific problems need to be tackled which will require “convergence research” across the social, natural, environmental, computing and information sciences, and engineering in order to address the intersection of natural, social, and built systems which together constitute cities. Achieving this ambitious scientific goal will require that a new generation of urban sustainability scientists be trained in novel ways. We stand ready to help the NSF contribute to the educations of SUS scientists.

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Simon, D., Palmer, H., Rise, J., Smit, W., Valencia, S. (2018) The challenges of transdisciplinary knowledge production: from unilocal to comparative research. *Environment and Urbanization*, 30: 481-500.

Solecki, W., Seto, K.S., Marcotullio (2013) It's time for an urbanization science. *Environment*, 55:12-16.

Vandecasteele I., Baranzelli C., Siragusa A., Aurambout J.P. Eds (2019) *The future of Cities: Opportunities, Challenges and the Way Forward*. Luxembourg: Joint Research Centre, European Commission.

Waldrop, M.M. (2019) The quest for a sustainable city. *Proceedings of the national Academy of Sciences of the United States of America*, 116:17134-17138.

Wu, JG (2014) Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and Urban Planning*, 125:209-221.

Appendix A1. Workshop Agenda and List of Participants

Graduate Education for a *New Sustainable Urban Systems Science*: Designing a New PhD Curriculum Integrating Sustainability Science and Urban Science

School of Sustainability
Arizona State University (Tempe, Arizona, USA)
September 19 – 20, 2019

Conference Information

It is by now widely recognized that humanity's success in transitioning towards equitable prosperity, achieving sustainable development and adapting to climate change will largely depend on what happens in urban areas. In January 2018 the National Science Foundation (NSF USA) issued a report articulating a “vision and a compelling research agenda for developing the next generation of sustainable urban systems science.”¹ The report identifies fundamental research questions which must be addressed “so that the transformative social and technological changes forecasted in urban areas may be harnessed to benefit society at all scales-local, national, and global.” The development of a transdisciplinary *sustainable urban systems science* is an ongoing integrative effort, building upon decades of research on cities and urbanization conducted by scholars across many disciplinary domains. It will also require the training of new generations of researchers who need to be educated in a manner consistent with the transdisciplinary research they are being called upon to conduct. *This conference is intended to design a curriculum (course content²) that can be a template for a PhD degree in sustainable urban systems science.* (The template can then be modified to fit the specific needs and contexts of Universities and research institutions worldwide.) A summary of the conference’s discussions, and a design for a PhD-level curriculum, will be presented in a jointly authored report to the NSF, which will in turn make the report available.

Organizer

José Lobo (School of Sustainability, Arizona State University) [jose.lope@asu.edu]

Dates

The conference will take place on Thursday, September 19 and Friday, September 20. Out of town participants are asked to arrive by the evening of Wednesday September 18; departure dates can be Friday evening, anytime Saturday (09/21) or anytime Sunday (09/22).

¹ <https://www.nsf.gov/ere/ereweb/ac-ere/sustainable-urban-systems.pdf>

² Methods, concepts, theories, modelling frameworks, types of data, modes of reasoning?

Conference venue, hosts and sponsor

The conference will be held at Wrigley Hall, the home of the *School of Sustainability*, Arizona State University (ASU). The School of Sustainability (SOS) is the first school in the United States dedicated to exploring the principles of sustainability.³ Established in 2006, the School offers BA, BS, MA, MS, Master of Sustainability Solutions, Master of Sustainability Leadership, Executive Master of Sustainability Leadership, and PhD degrees in Sustainability. The School of Sustainability is a learning unit of the *Global Futures Laboratory*.⁴ The conference is funded by the *National Science Foundation* of the United States, under the funding call “Conference Proposals on Concepts for Advancing Sustainable Urban Systems (SUS) Research Networks.”⁵

Welcome reception and meals

To uphold sustainability principles, all provided meals will be vegetarian. There will be a welcoming reception—light snacks provided—on Wednesday, September 18th, from 6:30pm to 8:30pm, held at the rooftop bar of the Graduate Hotel. (In accordance with Arizona State University regulations, alcohol will not be provided at the reception or at any of the meals.) [Hotel address: 225 E. Apache Boulevard, Tempe, Arizona. This is the hotel where out-of-town conference participants are staying at.]

Agenda⁶

If any participant would like to make a 10 minutes presentation on the content of a graduate curriculum on urban science or urban sustainability that he/she is familiar or has been involved with, please contact José Lobo.

Day 1 (Sept. 19)

8:30am	Light breakfast (at WGHL 481) ⁷
9:00am	Welcome to ASU/SOS & Introductions
9:30am	Welcome on behalf of the NSF: national SUS workshops and future directions of NSF
9:50am	<i>Sustainable Urban Systems Science</i> : what should this be? What questions define it? (Luis Bettencourt)
10:20am	Plenary Discussion
11:00am	Break

³ <https://schoolofsustainability.asu.edu/about/school-of-sustainability/>

⁴ <https://globalfutures.asu.edu/about/>

⁵ <https://www.nsf.gov/pubs/2019/nsf19032/nsf19032.jsp>

⁶ All plenary sessions will be held at 481 Wrigley Hall, School of Sustainability.

⁷ Catered by [Atlasta](#): coffee, tea, juices, fruit, yoghurt and granola.

11:15am *Sustainability Science education: current best practices?*

12:00pm Lunch⁸

1:15pm *Urban Science education: current best practices?*

2:00pm *What should a PhD in Sustainable Urban Systems Science include?*
Plenary discussion

3:00pm Break

3:15pm *What should a PhD curriculum proposal address/include?*

3:45pm Q&As

4:00pm *Small groups working sessions*

4:45pm Plenary session (reports)

5:30pm meeting adjourned

6:30pm Dinner⁹

Day 2 (Sept. 20)

8:30am Light breakfast (WGHL 481)¹⁰

9:00am Review of first day and agenda for second day

9:30am *Perspectives from U.S. Laboratories & Agencies*

10:30am *Small groups working sessions*

11:45am Reports from small groups discussions

12:15pm lunch (at WGHL 481)¹¹

1:30pm *Perspectives from U.S. City Halls*

2:45pm Break

⁸ At [Engrained Cafe](#) (0.25 miles/0.42 kms walk from School of Sustainability)

⁹ At [La Bocca](#), located 0.43 miles (0.69 kms) from the School of Sustainability.

¹⁰ Catered by [Atlasta](#).

¹¹ Catered by [Desert Roots](#).

3:00pm	Plenary discussion
4:30pm	<i>What should a PhD in Sustainable Urban Systems Science include?</i> Plenary session (summary discussion).
5: 30pm	conference ends
6:30pm	Dinner ¹²

- Background reports, articles and other relevant documents have been made available through a Dropbox to which participants have been given access to. Participants who want to share notes, presentations, sample curricula or training programs, or any other documents, please upload them to the Dropbox.

Participants

1. Marina Alberti (Director, Urban Ecology Research Laboratory, Director, Interdisciplinary Ph.D. Program in Urban Design and Planning, University of Washington) [malberti@uw.edu] [*participating remotely*]
2. Anni Beukes (Mansueto Institute for Urban Innovation, University of Chicago; Shack/Slum Dwellers International) [beukes@uchicago.edu]
3. Luis M.A. Bettencourt (Director, Mansueto Institute for Urban Innovation, University of Chicago) [bettencourt@uchicago.edu]
4. Luis A. Bojórquez Tapia (National Laboratory of the Sciences of Sustainability, Institute of Ecology, National Autonomous University of Mexico) [bojorquez@ecologia.unam.mx]
5. Christopher Boone (Dean, School of Sustainability, Arizona State University) [christopher.g.boone@asu.edu]
6. Shauna Brail (Director, Urban Studies Program, University of Toronto; Associate Director, Partnerships & Outreach, School of Cities, University of Toronto) [shauna.brail@utoronto.ca]
7. Liliana Caughman (Climate Action Plan, City of Portland) [liliana.caughman@portlandoregon.gov]
8. Weiqiang Chen (Institute of Urban Environment, Chinese Academy of Sciences) [wqchen@iue.ac.cn]
9. Dan Childers (Director, Central Arizona-Phoenix LTER Program, Co-Director Urban Sustainability Research Coordination Network, School of Sustainability, Arizona State University) [dan.childers@asu.edu]
10. Melissa Dumas (Urban Dynamics Institute, Oak Ridge National Laboratory) [allenmr@ornl.gov]
11. Luter Gavin (Managing Director, UniverCity Alliance, University of Wisconsin-Madison) [gavin@cows.org]
12. Nancy Grimm (School of Biological Sciences, Arizona State University) [nbgrimm@asu.edu]
13. Braden Kay (Director, Sustainability, City of Tempe) [braden_kay@tempe.gov]
14. José Lobo (School of Sustainability, Arizona State University) [jose.lobo@asu.edu]

¹² At [Pita Jungle](#) restaurant, located 0.3 miles (0.48 kms) from the School of Sustainability.

15. Zachary Neal (Urban Studies and Network Science, Michigan State University) [zpcneal@msu.edu]
16. Deirdre Pfeifer (Director, Urban Planning Program, School of Geographical Sciences and Urban Planning, Arizona State University) [deirdre.pfeiffer@asu.edu]
17. Anna Perreira (Faculty of Engineering and technology and Department of Architecture, University of Guyana) [anna.perreira@uog.edu.gy]
18. Pushpa Ramakrishna (Program Director, Division of Undergraduate Education, Directorate for Education and Human Resources, National Science Foundation) [pusramak@nsf.gov]
19. Aromar Revi (Founding Director, Indian Institute for Human Settlements) [arevi@iihs.co.in]
20. Mark Roseland (Director, School of Community Resources and Development, Watts College of Public Service and Community Solutions Arizona State University) [mark.roseland@asu.edu]
21. Michael E. Smith (School of Human Evolution and Social Change, Arizona State University) [mesmith9@asu.edu]
22. Jason Schupbach (Director, The Design School, Herberger Institute for Design and the Arts, Arizona State University) [jason.schupbach@asu.edu]
23. Eleanor Stokes (Goddard Space Flight Center, University of Maryland) [eleanor.stokes@nasa.gov]
24. Shade Shutters (Decision Theater, Arizona State University) [shade.shutters@asu.edu]
25. Deborah Strumsky (School for the Future of Innovation in Society and School of Sustainability, Arizona State University) [deborah.strumsky@asu.edu]
26. Jingle Wu (School of Sustainability, Arizona State University) [jingle.wu@asu.edu]
27. Abigail York (Center for Behavior, Institutions and the Environment, School of Human Evolution and Social Change, Arizona State University) [abigail.york@asu.edu]

Suggested background readings

A dropbox will be created with several reports and papers that conference participants are encouraged to read (or at least skim over) in preparation for the meeting. The following documents should be given prioritized.

1. Sustainable Urban Systems: Articulating a Long-Term Convergence Research Agenda. (2018) Washington, DC: National Science Foundation. (<https://www.nsf.gov/ere/ereweb/acre/sustainable-urban-systems.pdf>)
2. Science and the Future of Cities: Report on the Global State of the Urban Science-Policy Interface. International Expert Panel on Science and the Future of Cities. (2018) *Nature Sustainability*. (https://www.nature.com/documents/Science_and_the_future_of_cities.pdf)
3. Know Your City: Slum Dwellers Count. (2018) Cape Town: Shack/Slum Dwellers International. (http://knowyourcity.info/wp-content/uploads/2018/02/SDI_StateofSlums_LOW_FINAL.pdf)
4. A Social-Ecological-Infrastructural Systems Framework for Interdisciplinary Study of Sustainable City Systems (2012) Ramaswami et al., *Journal of Industrial Ecology*, 16: 801-813. (<https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1530-9290.2012.00566.x>)
5. Global change and the ecology of cities. (2008) Grimm et al. *Science*, 319: 756-760. (http://www.public.asu.edu/~nbgrimm/USEL/web/images/pubs/2008/Grimm_etal_Science_2008.pdf)

6. The quest for the sustainable city (2018) (<https://www.pnas.org/content/116/35/17134>)
7. Built Environment, Urban Systems, and Cities, chapter 11 of (2018) *Fourth National Climate Change Assessment*, Washington, D.C.: United States Global Change Research Program. (<https://nca2018.globalchange.gov/chapter/11/>).

Appendix A2. Questions to consider when proposing a new PhD program

- 1) Is there a new domain of research and practice not adequately covered by existing PhD programs?
- 2) Can existing PhD programs not be expanded or modified to cover the newly identified domain of research? Why not?
- 3) Does the proposed new Program cannibalize existing PhD programs? Does it supplant or render obsolete existing programs? Does it complement? (In which ways?)
- 4) Does the proposed PhD program require a new school or Academic unit? Can it be offered by an existing single academic unit? Jointly through existing units collaborating?
- 5) What type of students are expected to apply for the proposed new program?
- 6) What would recipients of the proposed PhD degree be able to do? Who or what will hire them?

Appendix A3. Sample Curriculum Content

A3.1 Curriculum Notes

These are the core courses for a PhD In Sustainable Urban Systems.

1. History of urbanization: form the earliest cities to the present
2. Fundamentals of urban economics/economic geography (agglomeration effects: what happens when humans agglomerate)
3. Fundamentals of urban sociology (neighborhoods and networks)
4. Fundamentals of urban ecology
5. Fundamentals of urban engineering (urban metabolism, infrastructure, transportation)
6. The City: identifying it, measuring it (the Modifiable Area Unit Problem; different types of data, different types of inquiry; remote sensing data; data on personal behavior)
7. Fundamentals of urbanism (synthesis course):
 - (i) human interactions are exchanges of material goods and information that take place in physical space;
 - (ii) the intensity, productivity and quality of individual-level efforts are mediated and enhanced through interaction with others (social networks);

- (iii) any human activity can be thought of as generating benefits and incurring costs (especially the costs of moving people and things in physical space);
- (iv) human effort is bounded;
- (v) agglomerated human activity requires biophysical assets and affects the biophysical environment;
- (vi) history matters: it facilitates and constrains (in cities history is made physical and social); and
- (vii) the size (scale) of a human agglomeration is both a consequent and a determinant of the agglomeration's productivity.

The use of the term “fundamentals” is to highlight that these courses will try to convey the main insights and concepts of the discipline in question: many details will not be covered. The emphasis is on “manner of analysis” rather than methodological choices/obsessions.

A3.2 Curriculum Notes

Theory (15 credits)

- Intro to sustainable urban systems science (3 credits)
 - Project management theory / practice/ tools (module)
 - Study the most recent IPCC report; WG I for science, WG II for impacts/urban
- Urban governance
 - Politics, policymaking
- Behavioral economics/insights
 - Empirical understandings of human behavior & modeling
- Critical infrastructure in cities
 - Energy, digital, physical infrastructure
- Population dynamics & demography
 - History of urbanization
 - Human geography
 - Demography

Methods (12 credits)

- Systems modeling / Python scripting
- Geographic information systems (GIS)
- Network analysis
- Community engagement and participatory research

Electives

- Urban Innovation: Analysis and Policy
- Urban Sustainability and Infrastructure
- Urban Politics and Governance

Culture & Cohort Building

- Co-curricular orientation & professional development skills
- Project-based/experiential learning integrated into courses
- Involvement in multi-year interdisciplinary projects
- Brownbags where faculty and students can share research & experiences

A3.3 Curriculum Notes

What needs to be part of a “sustainable urban science” curriculum?

- Design thinking – learning how to work with people, joint creation of knowledge
- Talking in multiple academic languages
- Systems thinking – view of processes is systems, what do you measure, measures of “progress” for cities (GDP/economics, SDGs, climate/carbon output, equity, life expectancy, human development index; capabilities, people should be able to pursue their lives as they choose)
- History of urbanization and complexity within cities – what concepts drive ordering space (looking at it through different lenses: urban form, social / political, what cities are used for)
- A comfort working across many different scales and dealing with complexity
- Fluidity with different institutions
- Local government finance / understanding
- Inter-locking systems/institutions/governance/behavior change/morals/ethics of city development
- Training students to develop agency/community organizing/social change
- Basics of engineering and sustainability (urban and industrial ecology, resources consumption, circular economy, transportation)
- Technology in cities (looking backwards & forwards: what does that mean for AV, sensing)
- Grant writing
- Experiential learning component
- Landscape ecology (urban as a land system)
- International / comparative

Design principles

- Input/output (different curriculum for students based on what they want to do)
- Flexibility (based on what the students know when they come in)

A3.4 Curriculum Notes

Design principle: a holistic approach towards thinking about what cities are.

Foundational courses

- fundamentals of complex systems
- history of cities and nature of urbanization

Focal areas

- Demography
- Urban ecology
- Sustainability Science
- Infrastructure & Transportation
- Urban Economics

Competencies

- Modeling
- Simulation
- Data Analysis