ABSTRACT
The role of prototypes is well established in the field of Design. There is however lack of knowledge about the fundamental nature of prototypes; there are different types of prototypes and they are sometimes difficult to define, for example: from low- versus high-fidelity prototypes, centered on evaluation or as support of design exploration. There have also been efforts to provide new ways of thinking about the activity of using prototypes, such as experience prototyping and paper prototyping. This paper aims at reflecting on efforts to provide a discourse for reflecting or understanding fundamental characteristics of prototypes in design and specifically the role of prototyping in design education. In this paper we showcase different materializations of the same prototype as background for prototype conceptualization. We view prototypes not only in their role of evaluation but also in their generative role in enabling students and designers to reflect on their design activities of exploring a design idea. The paper discusses the pedagogical methodology through a workshop that resulted in an exhibition named ‘Anatomy of a Prototype’. The work was formulated by the dissection of an interactive piece by exhibiting the role of the same prototype in different manifestations from problem solving through problem-finding to full documentation. The hypothesis is in praise of prototypes as the main vehicle for ‘research through design’.
BACKGROUND

Architecture, design in general, and prototypes are inherently related. Given that the design of the so called sustainable and ecological built environments will increasingly need proof of concepts through full scale working prototypes, which also integrate physical computing systems, designers’ repertoire of skills and knowledge needs to adapt to meet these challenges in professional practice. Will designers of the near future be not only professional designers, but also professional programmers and engineers? This is evident, for example, in the double meaning of the term ‘computer architecture’ which can refer to the way computers are built as well as to the way buildings are computed. Accordingly, architecture has been defined as ‘logic states in space and time’ (Frazer 1999). The built environment is rich with opportunities for embedding and integrating digital technologies to create responsive and adaptable systems. Physical computing, a term coined by Tom Igoe and Dan O’Sullivan, refers to systems that can sense and interpret data computationally and, in response, physically affect change (2004). The technical implementation of such systems requires a broad range of skills that span multiple knowledge domains—design, engineering, mechanics, programming and computer science, robotics, cybernetics, mathematics, electronics—just to name some. At the cutting edge of the intersection between these fields, highly inspiring projects are being developed that re-define the boundaries of architecture and computation, and which have strong motivating and inspiring effects on students of these fields, for instance ceilings that move and change color (Senagala and Vermillion 2009), walls that sense and emit light (Buente and Perry 2013), panels that fold in shape according to sound and acoustic qualities (Thune et al. 2012), or even completely immersive environments with parts that change, move, and reconfigure both locally and systemically (Beesley 2012). This brings us to another value proposition: professionally trained designers are in the unique position to orchestrate and integrate systems into a poetic “whole” that is more than the sum of it lower-level parts (Diniz 2012). A designer’s role is to integrate and this is where design adds value to an otherwise reductive process of breaking large problems into smaller problems and then simply solving them. Approaches in design process that still employ a linear workflow usually driven by an interpretation of program, site, and conditions carried through stages of conceptualisation; schematic design, and design development are seen out of date. Since the 90s, designers (Lynn 1999; Aranda and Lasch 2006; Liu 2005) started to define paradigmatic approaches in architecture design education, and as a result architecture as a design discipline changed methodologies: the notion of ‘processes’ being more interesting than ‘ideas’ (Zaero-Polo 2003) was a key change to design thinking. Extensive research into digital pedagogical models and techniques and their relations to studio design has been developed by various researchers as a foundation for design education and pedagogy (Knight and Stiny 2001; Frazer 2002; Kvan et al. 2004; Oxman 2008). From these studies and frameworks emerged the formulation of digital design models in studio teaching, the conceptual content and vocabulary of digital design. In their research the transition and transformation of concepts such as representation, precedent-base design and its replacement by concepts like generation, mutation, animation, and performance-based design and behaviour was
solidly demonstrated (Lynn 2003; Kolarevic and Mallaawi 2005). In view of the shift of the design process towards the digital, it is important to make the point that today designers do need to have an augmented palette of skills that includes scripting and physical computing knowledge. However, what this paper presents is an approach where hand-on prototypes reposition designers as professionals that are uniquely aware of human needs as they relate to space, scale, effect, aesthetics, and experience. These topics and concerns should be at the forefront of the students’ efforts when discussing digital and physical computing in design, rather than devoting most time to overcoming technical glitches with scripting or electronics—in other words, ‘prototyping with physical computing, without the computing’. While this framework seems to shut the door on prototyping systems with sensors, wires, microcontrollers, motors, and the like, in this paper we argue we do recognize the value in experimenting, testing, and simulating with iterative prototyping. In this sense, fabrication (e.g. model making, which the students are usually skilled at) becomes a useful vehicle for testing parts-to-systems aggregation, details, scale, and effects. This research tests a design experiment in a very short period of time where students focused on repetition of one prototype design and a limited material palette. We also used extremely simple electronic components, such as microprocessors, sensors and servo motors, and as a result, these systems would be deployed to serve design that is focused on human-user experience.

THE PEDAGOGICAL APPROACH

Anatomy is commonly defined as the “the science of bodily structure” (OED 2006). We use this notion both literally and metaphorically to sketch an anatomy of prototypes, to “dissect” or uncover the fundamental dimensions along which to understand the role of particular prototypes in a design agenda. An anatomy is a description of possible shapes and structures; it shows how things can be organized. ‘The anatomy itself does not tell designers how to design prototypes, but it can inform them about the fundamental nature of prototypes and the possibilities in thinking about them’ (Lim et al. 2008).

The workshop and consequent exhibition was formulated by the dissection of an interactive piece, by exhibiting the role of the same prototype in different manifestations: from problem solving through problem-finding to full documentation. The prototypes were developed by twelve students at the Xi’an Jiaotong-Liverpool University architecture department during a period of ten days during the summer break. The work was organized through a series of three materializations, 1: ‘Prototype: Outside-In’, 2: ‘Prototype: In-Action’, 3: Prototype: Inside-Out’. The methodology was organized mostly through hands-on prototyping development sessions supported by introductory and state of the art sessions delivered by the tutor and assisted by one teaching assistant that helped students with the sensing and actuators features of the prototypes. To test the design approach, the students built numerous prototypes, primarily to create parts that, when iterated in the three different materializations, could form different prototyping methods. The final prototypes were exhibited as part as a collective international
exhibition under the theme ‘Design and Research’. The full-sized installation of the prototypes provided an opportunity for further troubleshooting and student reflection on ten days’ work, which was conducted in a very compressed amount of time, but nevertheless resulted in well-crafted artefacts to demonstrate the cumulative effort.

MATERIALIZATION 1_ ‘PROTOTYPE OUTSIDE-IN’

In the first materialization of the exhibition we show the prototype as a ‘ready-made’ fully working product, an abstract machine representative and a manifested form of a ‘marketing design idea’. We argue that the purpose of designing a prototype is to find the manifestation that, in its simplest form, will filter the qualities in which the designer is interested without distorting the understanding of the whole. In this materialization the prototype works as an interactive garment. It displays the same prototype in a modular system small scale units (Figure 1) that close up according to visitor’s proximity.

![Figure 1](The prototype demonstrated the concept as part of an interactive garment in Materialization 1_ ‘Prototype Outside-In’.)

MATERIALIZATION 2_ ‘PROTOTYPE IN-ACTION’

In this section we show the prototypes as interactive experiences/experiments. The prototypes were replicated in a modular system of three interactive units (Figure 2), and each unit reacted by opening in various degrees according to varying proximity distance by visitors. In this materialization, the prototype not only acts as improving design as ‘problem-solving’, but in creating a space for designers to reflect upon the ideas, theories, logics, and implications of design in and through practice, that is to say, the intervention of an intellectual basis for ‘problem-finding’. A specific reference for this kind of approach for conceptual design is critical design, most associated in product and interaction design by the work of Anthony Dunne & Fiona Raby at the Royal College of Art in London. They posit the designer as a critically and materially engaged practitioner—a sort of ‘applied conceptual artist’. In addition to art, they state: “Critical design is related to haute couture, concept cars, design propaganda, and visions of the future, but its purpose is not to present the dreams of industry, attract new business, anticipate new trends or test the market. Its purpose is to stimulate discussion and debate amongst designers, industry, and the public about the aesthetic quality of our electronically mediated existence” (Dunne and Raby 2001).
In the last materialization, the prototype was materialized and displayed as a manual (Figure 3) and a documentary video (Figure 4). Theses two pieces fully documented all aspects of the ’making-of’ of the interactive prototype in the exhibition—from hardware to software implementation, assembly and materials, with testaments given by students and tutors revealing the ’prototype as a discourse or authorship’. The video is meant to be a fictitious narrative in the style of an elaborate scientific research project. The documentation, therefore, offers a poetic and playful reflection about the status of prototypes and design research in general. This ’spoof presentation’ ties with the writings of Bruno Latour, where he says: ’To guarantee success, the scientist is required to gather resources, talk with authority, convince others, and equip laboratories. Success is measured by attention, money, and confidence. All this explains how the domains of
science, technology, and society are kept apart’. This is what Latour refers to as a model of ‘diffusion’ where in the associations and translations are kept apart artificially. It is not simply that science is determined by technical or social factors; Latour recognizes the significant influence of class, the economic infrastructure, capitalism, business, gender, culture. Instead, he proposes that science and society are tied together ‘symmetrically’, face to face presumably in a janus-like relation of human and non-human resources. This leads Latour to ask who is really doing science, as this is not confined to bearded men in white coats in laboratories. Clearly there is a complex institutional mesh around science, linked to funding structures of research and enterprise, with relations of production in place to protect some of the interests described. Statistics of money spent on research and development programs and educational provisions are revealing in this connection. Success or failure rests on these factors of visibility. ‘All laboratories are not equal before God’, says Latour. It is no surprise to learn that budgets remain proportional to amounts of interest generated. Latour concludes that success rests on the ‘presence or absence of already aligned interest groups’ (Latour 1999).

**Figure 3**
The prototype was documented by a series of technical drawings, and scaled mock-ups documenting its full functioning performance in Materialization 3, ‘Prototype Inside-Out’.

**Figure 4**
Caption images of the satiric video documentation of the making of the interactive piece.
CONCLUSIONS AND IMPLICATIONS OF ‘PROTOTYPING EMBEDDED DESIGN RESEARCH’

In this paper and through this design workshop initiative, we take the design research described by Faste and Faste (2012), as a combination of process and research that culminates in an artifact as the embodiment of design research knowledge (e.g., an object, process, interaction, experience). For this reason we refer to it as ‘prototyping embedded design research’ the knowledge generated is contained in the cognitive processes and artifacts of the design activity performed. Research through design is not limited to traditional research documentation and, in this regard, is closely related to research through practice in disciplines such as studio art where similar processes result in the creation of experienced artifacts (Koskinen et al. 2011). Because designers use research to understand the topics they are working on as a process of creation and self-reflection, they are able to improve their design research practice in ways similar to diagnostic design research methods. A major difference, however, is that design process knowledge is embedded in the designer’s internal toolkit as well as in the external world as a result of the generated designs. In this regard embedded design research enables the enhanced performance of future design action through knowledge disseminated through broader means than that of traditional research. It encompasses artifacts in addition to indirect oral traditions, and propagates in aesthetically and emotionally meaningful ways. Indeed, design objects are presented as arguments for interpretation by their intended audience, forming a critical triad of discourse between the designer, the artifact, and the social environment that the artifact influences. As Biggs (2002) observes, “This implies the notion that the artifact can embody the answer to the research question.” Embedding knowledge in the designers’ activity not only enhances design research, it plays a vital role in the dissemination of knowledge across all forms of experience.

What this experiment shows is that instead of asking students to solve a particular design problem, and define a formal representation criteria, we asked them to define essentially a prototype taxonomy. That is, through one prototype that can be utilised to facilitate a variety of solutions. It is a way of thinking that structures and relates tangible systems into a design proposal removed from digital and analogue tool specificity and establishes an holistic relationship between properties within a system. It asks students to start with the design parameters and not preconceived or predetermined design solutions. It is therefore the hope of this research to suggest that prototype-based methodologies can give assistance to designers to structure their own thoughts. But as with any design method of working the set of tools used influences the designer’s thinking. Ultimately these are only research practices and we expect that our proposal will lead to more discussion on comparing different roles and effects of prototypes in design, perhaps by adapting new and unconventional ways of constructing prototypes not yet so commonly used in traditional design teaching processes. This proposal is based on a review of related literature in addition to our firsthand experience as ‘researchers through design’. It is our hope that the approach we have taken helps to clarify and simplify the process of
describing the nuances of design research, especially to those interested in expanding the creative fringes of design research practice.

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Nancy Diniz is a registered architect, educator and researcher. Before joining Rensselaer Polytechnic Institute she held several academic positions in China, UK, Italy and in Portugal in the areas of Architecture, Interior Architecture, Environmental Technology and Interactive Design. Nancy has published and exhibited her work widely namely at Milano Expo 2015, Venice Biennale, Lisbon Architecture Triennale, ISEA, Dislocate, and Cornell University. Her main research and teaching interests question traditional scale boundaries between design disciplines: Product Design, Architecture, and Computer Science. Lately she has been prototyping modular and scalable systems that go from garments to envelopes of buildings, exploring notions of wearable and mobile materials with real-time environmental information exchange properties. Her research has also included developing digital tools to assist conceptual design processes. She has worked with augmented reality, free-hand 3D virtual modeling, and creating tools that allow for time-based mapping, analysis and visualization of invisible, unquantifiable and temporal data.