Visualizing complex systems

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VISUALIZING COMPLEX SYSTEMS

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INTRODUCTION

Chiara L. Remondino
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The multi-faceted nature of information brought the society towards a radical change, especially in this era where data production and collection are reaching levels that could not even be imagined until a few years ago. From relations to components, from process to systems, the importance to make these elements more visual became essential to enable new scenarios, innovative systems, and creative mindset in an educative and formative way.

The ability to collect, cross-check, visualize and study quantitative and qualitative information about phenomena and their patterns is itself at the core of the project, becoming strategic for enabling new systems thinking and their design application. Identifying the relationship between components, thus guaranteeing personal expression, horizontal communication and visual thinking, is the first step to enhance a more conscious and transparent decision-making process with a perspective of sustainability.

This book aims to offer an overview of the discipline of data visualisation and its application in the investigation and communication of complex systems, also thanks to the analysis of the posters exhibited during the visual exhibition that took place from 23 to 28 October 2018 in Turin, in the frame of the RSD7 - Relating System Thinking and Design symposium.

Visualizing complex systems

Chiara L. Remondino
Barbara Stabellini

Visualise: see tr. [visual der.]. - Make it visible. Build a visual image in the mind. However, today, a broader representation is given, including the graphical representation of data and concepts, from internal mental constructs to external artifacts to support decision making. Visualisations represent powerful cognitive tools that surround our daily lives (Bonsiepe, 2000) connecting two worlds, physical and digital, bringing the gap between them closer and closer, playing a crucial role in the exploration and communication of information. "A picture is worth a thousand words".
Today we live in a world full of data and our daily lives depend to a large extent on our ability to process the information contained in them efficiently. However, technological advances have led to a situation where we collect far more data than we can understand, a phenomenon otherwise referred to as "information overload". We therefore need to change our perspective so that visualisations are not simply defined by the technology they involve, but rather by the relationship with the purpose and context for which they are designed.

From a design point of view, visualisations represent the process that goes from data to knowledge (DIK continuum). In fact, they are able to collect data, information and knowledge (materials) and visualize them to create new knowledge (objective) (Masud et al., 2010). Furthermore, Wurman suggests that one of the main purposes of information representation is to help readers avoid the "black hole between data and knowledge" (Wurman, 1989); thanks to the relationship with context, unstructured information (reality and complexity) can be encoded into structured information and thus knowledge and insights for a more conscious decision making process based on data, a process based on a new model such as: DYKW (Data, Information, Knowledge, Wisdom) [Fig. 1].
Visualisation thus becomes a fundamental tool and medium for clarifying and simplifying information, favouring the exploration of complex phenomena, enabling the observer to have a profound understanding of the causes and effects of specific choices, comparing the effects in the most diverse situations, showing relational changes and distributing chaotic information in ordered and organised structures. From this scenario it is possible to deduce the importance and urgency of showing data, but above all of making them coherent and comprehensible, encouraging the eye to comparison and detail, avoiding distortions or gaps. Behind these abstract maps, there is the knowledge that it is not enough to choose a format, rather than a color, but instead you need to think about the message to be conveyed and the organization of variables and categories based on the goal you have set. Behind these abstract maps, one recognizes that the greatest value of an image is forcing us to notice something that we would not expect to see. Behind these abstract maps is the awareness that their intrinsic goal is to guide the observer in exploring and understanding the potential and

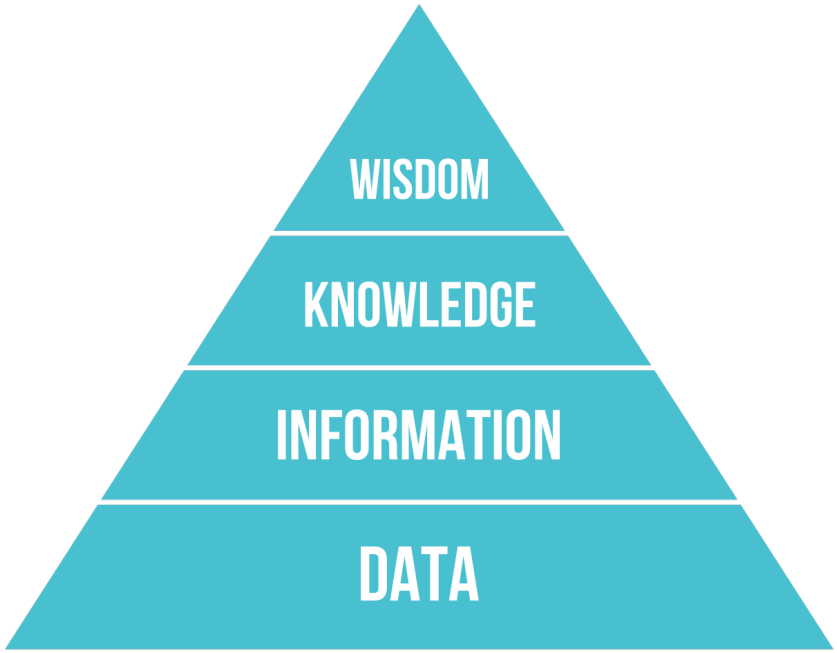

Fig. 1 DYKW model (Data, Information, Knowledge, Wisdom).

characteristics of a territory (Corraini, 2017). Awareness acquired, moreover, by the possibility offered to the reader, also thanks to the application of the basic principles of interaction design, to undertake and intervene on the very construction of one's own interpretative path: a freedom of choice of reading paths, a possibility to build comparisons, historical causes, intuit subsequent evolutions (Colin & Troiano, 2014).

Aware of the possibilities offered by the tool, the implications and the possible and desirable effects on the actions and decisions of everyday life, there is now an urgent need for the participation of companies, organizations, administrations, the individual, as well as the community, a fundamental participation that becomes a lever for change in order to create original and innovative tools that can be integrated with traditional systems of mapping and analysis, less invasive tools and, at the same time, with faster turnaround times. There is a need for a new graphic alphabet, in a framework of functional rigor (Colin, 2014), to find the right code to give a visual order and visually synthesize the complexity, synthesizing this complexity to convey messages and qualitative narratives (Ciuccarelli, 2014). We need a language with the ultimate goal of sharing knowledge, opening up the boundaries of communication in ways that until now have been unexplored.

Multidisciplinarity: this is one of the most strategic and successful approaches for all this to happen, an approach that actively involves different disciplines, from technical-scientific to statistical sectors, from the world of social sciences to urban planning, up to the inclusion of artistic sectors and more oriented to design, arriving at the expansion of the traditional definition of digital humanities.

Inspirations and principles of information design

"Information is the good that produces knowledge, the vehicle of a signal that can trigger a process. Knowledge is belief produced by information" (Dretske, 1981) states the philosopher F. Dretske in his book Knowledge and the Flow of Information. The last face of information design is represented by the phenomenon of big data. For this reason, the practice of visualizing information, data and so-called big data is becoming essential for their comprehension. This activity is fuelled by continuous technical, creative, procedural and taxonomic experimentations towards a constant re-elaboration and definition. In this regard, in 1987 McCormick, DeFanti and Brown defined visualization in the digital context as a computational method, a tool that "transforms the symbolic into the geometric, allowing researchers to observe their simulations and calculations. Visualization offers a method for seeing the invisible. It enriches the process of scientific discovery and promotes deep and unexpected visions. (McCormick et al., 1987)

Card in 1999 defines this practice as the use of computer-supported, interactive visual representations to amplify cognition;

cognition that takes on the meaning of acquisition and knowledge. He takes up, in his support, what Hamming wrote in 1973 about computational systems, adapting it to visualization, defining what will be an axiom for many in this field, that is, "the purpose of visualization is insight and not image" (Card, 1999).

Edward Tufte in his book The Visual Display of Quantitative information defines the three axioms of visual representation, stating that "a visualisation must be able to communicate complex ideas with clarity, precision and efficiency", and coining the term "chartjunk" or "junk tables" to identify backwards, all those works that overlap the objective of describing information, artistic and aesthetic ambitions, a thought clearly inherited from Bauhaus functionalism and influenced by the consideration of Adolf Loos "ornament is a crime", a thought destined to re-emerge periodically in history, defining a particular balance between the company system and the role of the designer.

There are also different authors who, based on their background, methodological approach and field of action, formulate and set new boundaries, contributing to the enrichment and specification of this domain. J. W. Tukey says "the greatest value of a graph is to force us to notice things we never expected to see", while Alberto Cairo says "any visualization is a model", a model hopefully distinguishable for truthfulness and clarity of information, for functionality as a guide to a correct interpretation of information, for depth of content, must then be enlightening ensuring an improvement in knowledge and finally pleasant from an aesthetic point of view (Cairo, 2016) because, as D. says, "the most important value of a graph is to force us to notice things that we never expected to see", while Alberto Cairo says "any visualization is a model", a model hopefully distinguishable for truthfulness and clarity of information, for functionality as a guide to a correct interpretation of information, for depth of content, must then be enlightening ensuring an improvement in knowledge and finally pleasant from an aesthetic point of view (Cairo, 2016) because, as D. A. Norman "aesthetic pleasantness is important because attractive and pleasant things help us to invest a little more effort in understanding how to use them" (Norman, 2004).

The brain finds it much easier to process information if it is presented visually than in words or numbers. The right hemisphere recognizes shapes and colors, while the left hemisphere processes information in the form of text or tables in a more analytical and sequential way. Reading the latter requires a considerable mental effort, as opposed to the visual ones that can be easily grasped in less time and in a more effective way. The brain thus identifies patterns, proportions, relations that would otherwise be difficult to manifest.

Accessible, intuitive, visual tools can make a difference by enabling people to understand complex systems and phenomena and find creative solutions, thus obviating what Robert N. Proctor

calls agnotology (Proctor & Schiebinger, 2008), i.e. the study of ignorance and doubt induced culturally by the absence of knowledge or even by the more contemporary problem of information overload characterized by the presence of more and more data, often inaccurate and therefore misleading.
Information visualizstion is becoming more than just a set of tools, technologies and techniques for understanding the meaning of data sets. It is emerging as a stand-alone medium. A guaranteed visual space, a clear and simple abstraction process to guide the observer to the discovery and exploration of physical space.
In this regard, the work Design for Information by Isabel Meirelles identifies the cognitive principles underlying the process of acquiring information, which can be summarized as follows (Meirelles, 2013):
— to remember information;
— to convey meanings;
— increase working memory;
— facilitate research;
— facilitate discovery;
— support perceptual inference;
— improve detection and recognition;
— provide real and theoretical models;
— provide an aid to data manipulation.

To enable a visualization to achieve these goals, there are several requirements and constraints implicit in its development that go beyond the mere creation of a reasonable and operationally functioning solution. As in most other fields related to design (architecture, product design, fashion,...), the visualization of information seeks to achieve a functional balance between aspects of utility, solidity and attractiveness, or in their original Latin form, utilitas, firmitas and venustas (Moere & Purchase, 2011).
The concept of "utility", in particular, corresponds to the classical notions of functionality, usability, utility and other quantitative performance measures. In visualisation evaluation studies, these aspects are generally defined in terms of effectiveness (the accuracy and completeness with which users perform specific tasks) and efficiency (the amount of resources spent in relation to the effectiveness criterion).
"Solidity" is about reliability and robustness. In the context of information visualization, and in accordance with the focus on visual form, robustness refers to the quality of the display presentation algorithm. In detail, it describes the characteristic that allows the correct functioning of the visualization, its connection to the dataset and the possibility to reproduce it easily or to improve it in case of need.
Finally, "attractiveness" refers to what is related to "aesthetics": the appeal or beauty of a given solution. In this context, it is important to underline that aesthetics is not limited exclusively to the visual form, but includes aspects such as originality, innovation, novelty or other more subjective factors that can understand the quality of the user experience.
It follows that the ability to visualize complex information, today, no longer

refers exclusively to the communication of quantitative information, but mainly concerns the world of visual narration of values and qualitative data (Scagnetti et al., 2007), no longer a purely strategic action at the level of marketing but a movement aimed at increasing the collective knowledge of the society in its complexity.

Quantity and quality

Starting from a system that sees data properly selected, organized, correlated and measured on a quantitative level as a fundamental input, the importance of a "naturally" qualitative output emerges; an output that finds an answer in the visual representation of the system itself. This change of perspective further amplifies the need and the urgency of redesigning the economic and business, personal and social, environmental and cultural systems for their components, always fuelling new design challenges capable of identifying unprecedented correlations between the variables at stake.

However, extracting the maximum potential from the data, aggregating them and correlating them to a specific territorial context, is not so simple. Most of the projects developed to date have the tendency to be mainly representations of a state of the art, not always useful to activate subsequent decision-making processes, thus limiting the discipline of design to a simple decoration. But it is thanks to design that, through processes and methods, styles and languages, it is able to create a real syntax, to be understood in a broad sense and not only linguistic, giving meaning to the information, but especially to the system chosen; a system made of visible elements, as well as invisible components, where even the absence of perceptible data, takes on a tangible value, like a "silence consent". In this way, "if we build or reconstruct that network of relationships, then the information begins to offer us an overall view of the world".

It is not difficult to imagine for the near future collaborative and completely transparent companies, administrations and companies able to provide their employees, customers, stakeholders and citizens with an all-round view of the surrounding reality. A quantum/qualitative vision that from a moral and ethical point of view develops a triple condition: availability, accessibility and accuracy, as part of a holistic strategy to support the management of the territory. A strategy that focuses on information as a product and service, a fundamental strategy in order to enable a collective knowledge of society. The system as a whole thus achieves a new balance capable of offering a frequent cross between wide-ranging cultural dynamics and pragmatic innovations.

However, it can be very difficult for non-experts to understand or make formal representations of analytical data. Mapping data in the right form, with the right tool requires technical, design, graphic and communication knowledge. Bad design can blur the real meaning of data, distorting reality

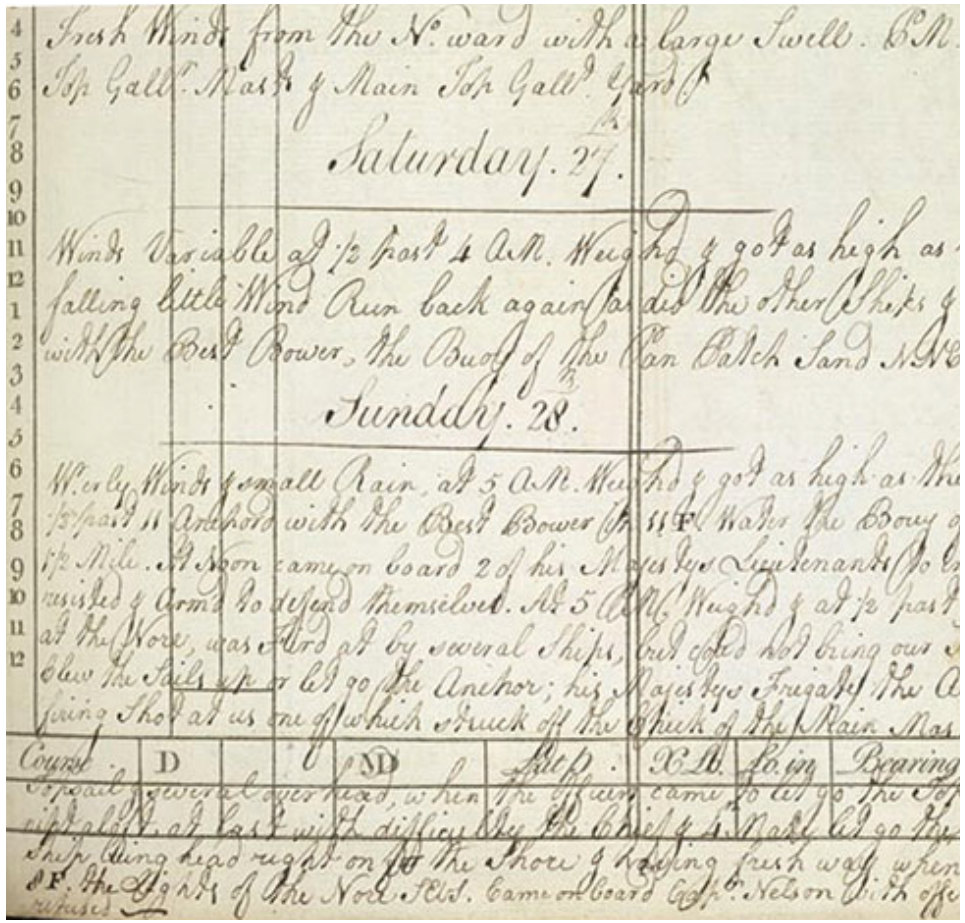

Fig. 2 Rochester Ship's Diary (1709)

unequivocally and causing obvious activities that are economically, socially and environmentally unsustainable. More visual tools, applications and processes that can be contextualized and contextualized can help to stimulate insights that can be interpreted in such a way as to trigger behavioral mechanisms of reaction. In this scenario, in the common sense, the data visualization aims at:

— to enable users to share a common language;

— to provide an overview of the state of the art at a strategic level;

— to trigger a more transparent mechanism between cities, research centres and organisations in general with a view to planning/participating.

Whether they are analog or digital, the best experimentations since ever are those carried out within a specific context. For this reason it is of fundamental importance for organizations as well as for citizens to keep track of all that the environment offers in the form of data and information. The environment is the context. The environment produces spatial, temporal, personal, collective data, but above all it relates them, contextualizes them, answering definitively one of the key questions of the visualisation "Compared to what?" (Tufte, 1983). Data thus becomes raw material, on the one hand enabling a continuous transformation, and on the other encouraging new projects, new visions that can be shared only if made visible.

Scientists, amateurs, national and international institutes have always been interested in understanding and forecasting weather conditions. Weather variations, mapped by professionals, individuals, sensors or other technologies, have become, have been, and are now, key material in the foresight of global climate change. In this process, sailors' observations have been the lifeblood for the development of the first oceanic and wind maps, as well as the diaries of the captains of the East India Companies' ships. It is 1709 when the ship Rochester sailed from Great Britain to China and its captain noted in detail in his diary drawings of ships, wildlife, native plants and particular places, recording their location, movements and climatic conditions [Fig. 2]. Today, the availability of real-time data allows scientists to complete precisely that work that began centuries ago, capturing the dynamic nature in our global system in interactive and dynamic maps; an example is the NASA project, which shows, through a clear and effective visualization, the trend of ocean currents between 2005 and 2007 detected through the use of satellites.

Another area that is strongly involved and interested in everything related to data visualization is that of healthcare, as an integral part of the continuous improvement of the well-being of society in its broadest sense. In this case, history shows us how sometimes visual representation can help, for example, to find causes and effects of diseases, or how the geographical distribution of infections

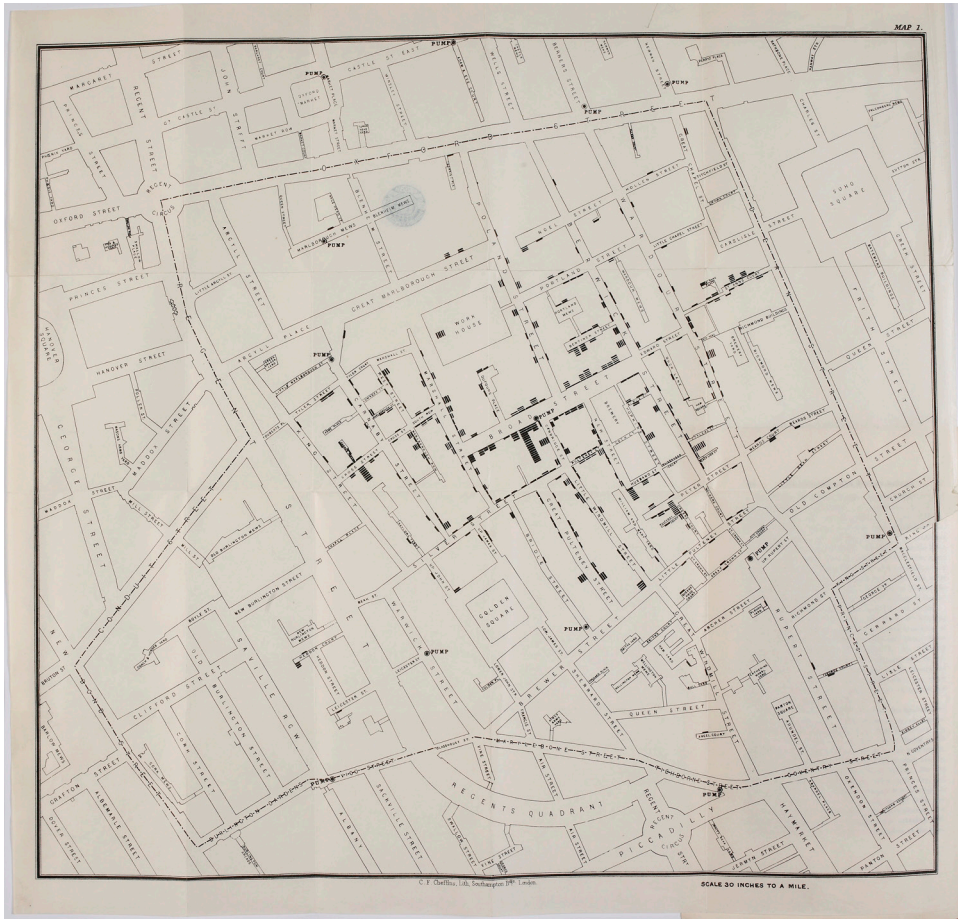

Fig. 3 On the mode of communication of cholera (J. Snow, 1853)

allows to monitor their spread if not the identification of the local environmental trigger. Perhaps the greatest contribution in this scenario is that made by Dr. John Snow who, in 1853, mapped all the deaths caused by cholera, highlighting, in what can be called a "ghost map", the right location on the territory of the water pumps, officially demonstrating that the epidemic had not been spread by the Thames, but by the water contaminated by human waste passing through the city aqueducts and thanks to the mapping he was able to identify the distribution pump of contaminated water [Fig. 3].

Still today, the mapping of the dynamics of the health system is decidedly important, even more so if it is connected to other specific socio-demographic data to offer a clear and objective scenario of the different clinical situations in the world, from a global level to a more detailed and local one.
Maps and cartography in general have always been closely linked to the world of mobility research, and not only with regard to the display of routes or directional infographic signs. The analysis and visualization of digital traces, whether personal or collective, are an aid to a continuous and renewed reading of society. The pioneering ORION (On-Road Integrated Optimization and Navigation) initiative carried out by UPS dates back to 1980 and, through appropriate sensors, UPS began to monitor all its vehicles, recording their speed, direction, braking times and other performance [Fig. 4]. The fundamental part of this vision was that from the very beginning, all the information collected was not only used to monitor daily internal performance, but also to redesign routes, optimise fuel consumption and reduce carbon emissions into the environment. Energy consumption, if we consider the environment as the context, is in fact one of the hottest topics today. The increasing availability of energy data allows people to determine how they use it by defining their impact on the environment, also linking this information with other data sets such as public transport, technology, production.
GPS, wi-fi observations, geo-referenced content, social networks, smartphones in general, the digital revolution, the ubiquity of the tools for mapping daily dynamics, define a concept of data that goes far beyond the simple indication of number. Today, data represents real life, a snapshot of the world, at a precise moment in a precise place, in effect a photograph. The reading of this "shot" obviously changes according to the visual form assumed, but it is only the context that will completely change the perspective. The interpretation of the dynamics between individuals, companies and territory in a continuous and dynamic pro-active and retroactive mechanism is the key to enabling new development policies. Identifying recurring patterns or altering factors allows the understanding of two distinct but complementary phenomena: attractiveness and pulsation (Prophet, 2016). The first derives fundamentally from the spatial distribution of users and the density of their digital interactions

Fig. 4 ORION System (UPS, 2013)

and social activities; the second refers more specifically to the attractiveness over time considering also the variations due to reactions triggered by events and disturbing or enabling events specific to the context. Graphically representing the dynamism of these phenomena becomes strategic for all those activities related to the urban system, tourism, economic, but also activities related to the world of mobility and the energy sector. To graphically represent the dynamism of these phenomena means to bring out decompositions, groupings by similarities, differences or possible comparisons between all the elements at stake.
Companies should therefore embrace complexity, because complexity is the hallmark of our time. The contemporaneity of the inevitable change dictated by the digital revolution, is causing the equally inevitable common approach on the part of companies to always and only use technology as a single answer, without spending enough time in the pragmatic definition of real problems, real needs or possible opportunities of the information assets in their possession. Opportunities dictated by all the possible hybridizations between technology and the humanities, between science and design, with the original aim of taking the conversation to a higher level.

Research and exhibition

This work collects the contributions exposed during the RSD7 conference in the framework of the exhibition "Visualizing complex systems" [Pics. at the end of the chapter]. These contributions come from the most diverse university faculties and cover an international panorama that goes from the United States and Canada to India.
The criteria that guided the selection of contributions were as follows:
— the role of visualisation in investigation, communication or project development;
— the role of communication visualisation in complex systems;
— functionality of the visualization with respect to the exposed topic;
— clarity and efficiency.
Contributions, from data and process visualisation to giga-mapping, from visual representation of part-whole relationships to visual tools for decision making, can be categorised in the following macro-areas:
— experimentation and methods;
— education;
— healthcare;
— city;
— territory.

Experimentation and methods

Many researches have already tried to identify methods to better represent complexity, researches that have involved different disciplines and for different purposes too.
Whether they are taxonomies or modes of representation useful to complete a process, they all find in the graphic representation and visualization of the collected data a strong point to enable a higher understanding of the phenomenon investigated.
There are four contributions collected in this section. They range from research

and definition of 16 visual models to represent complexity, to visual strategies to improve the usability of existing decision-making tools, from experiments through the use of chord diagrams representing the relationships between different stakeholders, to the identification of a way to describe almost anatomically a system.

Education

"We are a visual and symbolic species" (Cairo, 2012), says Alberto Cairo. Everything that our senses perceive and capture is transformed in our minds into simple and easily manageable representations or symbols, verbal and textual symbols, mental images and visual schemes. The affirmation of Cairo therefore focuses on the need to enable knowledge and understanding through the use of visual forms, graphics, diagrams, underlining how these are much more effective than lists of data, statistical formulas, algorithms and the now almost obsolete reports.

In this context, education finds a wide space for action, having the possibility of visually translating information that would be difficult to understand or memorize.

The contributions presented and categorized under this label show just how it is possible to transfer complex meanings using visual forms that very often make use of languages and playful tools to better support.

From lessons learned about the effects of one's choices through role-playing, to unconventional platforms for communicating environmental data, to more in-depth investigations into the future of education itself and the discipline of design, visualization becomes a versatile tool for all users.

Healthcare

As already pointed out, the health sector has a large amount of data to the point that visualisation tools can only become fundamental for their understanding or communication.

Three contributions have addressed this issue, and in each of them the world of representation takes on a different role. In fact, we move from the use of maps and diagrams to highlight the difference and disparity between the management and services offered by the traditional health sector compared with the possibilities of e-health, to maps with higher degrees of detail to analysis of the entire Indian health system, without forgetting the possibility of communication to convey important messages such as those of complexity in the system of organ donation.

City

The city has always fascinated research from many points of view; the exploration and narration of the dynamics that are established and develop in it are certainly one of the main sources of inspiration. Knowing its movements, understanding its flows, analyzing its metabolism, becomes fundamental to design on it in a coherent and effective way.

Two contributions specifically investigate visualization for these purposes, contributions that use forms of

mapping and abstraction with the aim of highlighting the relational potentials of the city and the spaces available in it.

Territory

Sometimes synonymous with context, environment. The detailed analysis of a territory is able to highlight specific phenomena and not, relate different environments and compare sectors. Conscious, exploratory, informative, projectual, the visualizations that place the territory at the center may have very different purposes, but all reflect sections that become easier to understand.
The contributions belonging to this category are mainly conceptual and infographic maps, graphs of specific case studies for regions or sectors of investigation that underline the importance of knowledge of the context in order to achieve sustainable design.

Today, we are faced with environmental, social and economic challenges that can be better understood and faced with greater security only by starting to act in a collaborative perspective, observing what surrounds us in a broader and more conscious way, starting, therefore, from the territory itself.

Fig. 1 The introduction of Panarchy's catalyst/ THE CHANGEMAKER PEDAGOGY


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What is the problem?
Who is involved?
How do we take action?


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Designing Designers
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T. Campbell, A. Lutterman
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How do we
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INDUSTRY
GOVERNMENT
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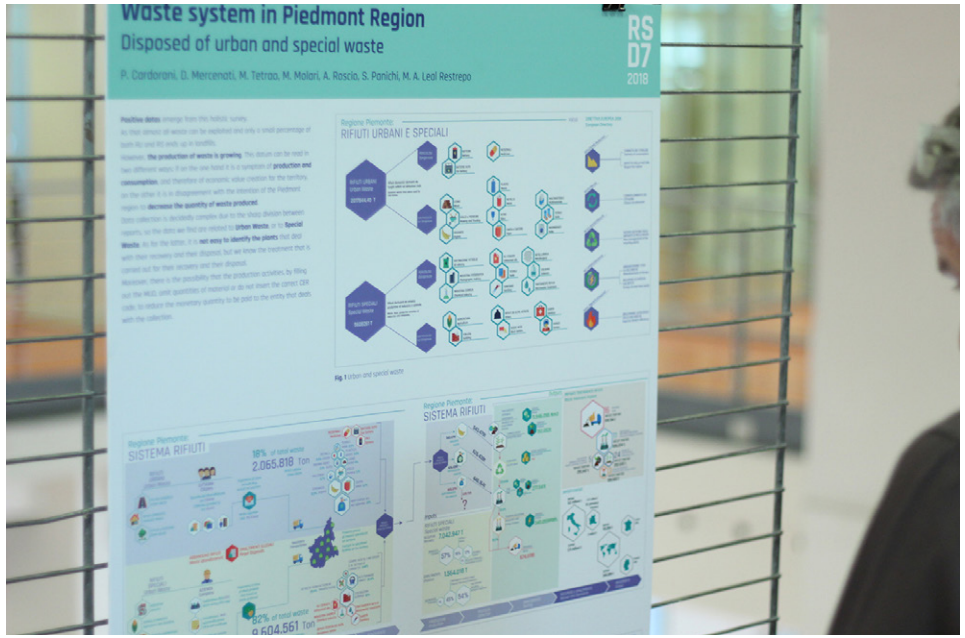
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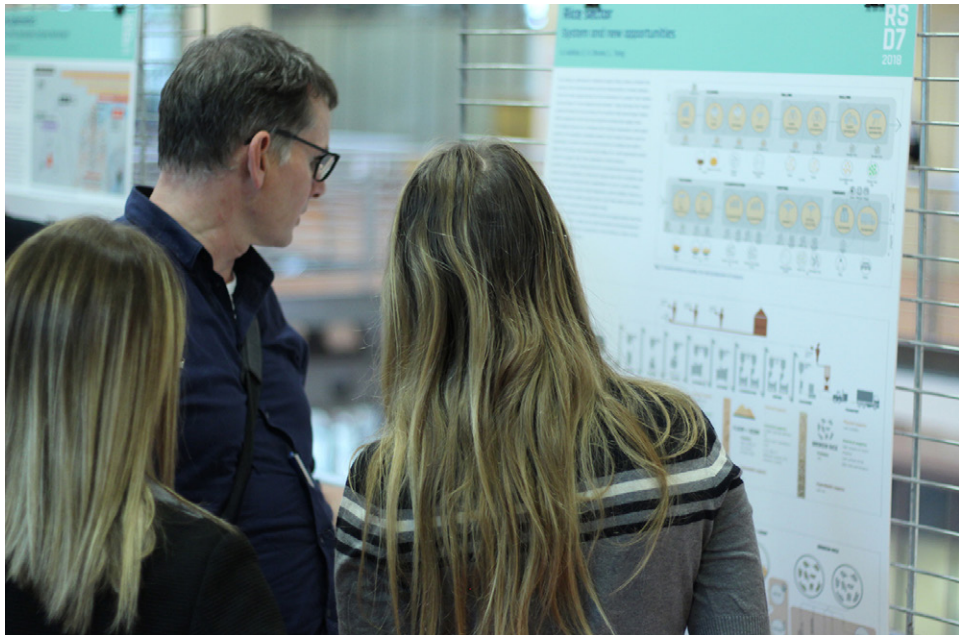
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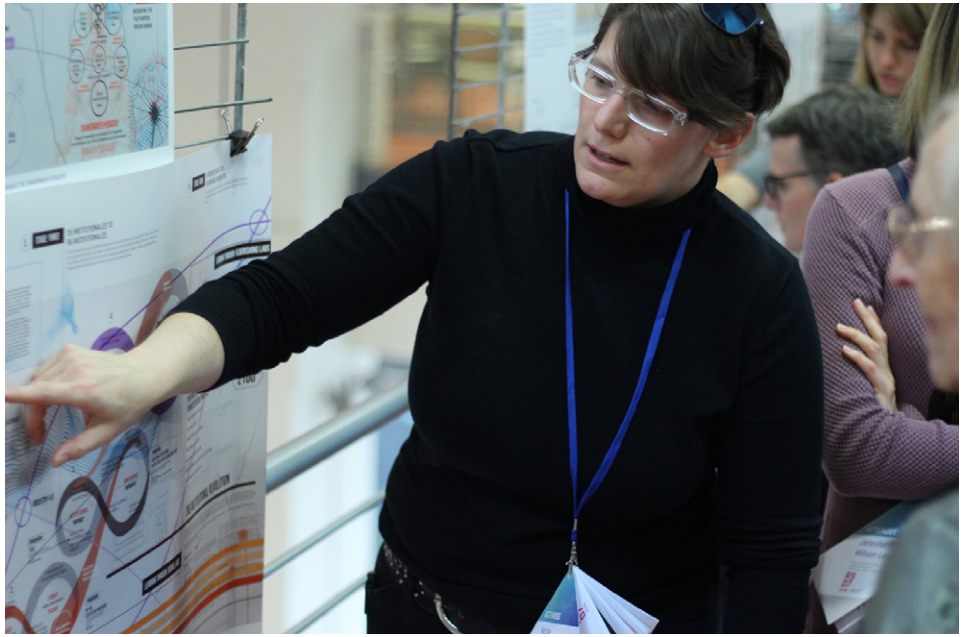

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