This paper was presented at The XXIII ISPIM Conference – Action for Innovation: Innovating from Experience – in Barcelona, Spain on 17-20 June 2012. The publication is available to ISPIM members at www.ispim.org.

Living Labs & Stigmergic Prototyping: towards a Convergent Approach

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Abstract: The aim of this paper is to contextualize design research within studies on self-regulating systems. Two state-of-the-art design concepts are considered: Living Labs and Stigmergic Prototyping. Living Labs are real-life environments for tests and experiments related to ICT. Stigmergy is an important concept in the study of self-regulating of collective intelligence. Stigmergic Prototyping refers to the recent use of self-regulating for design purposes. Both design concepts are closing the gap with evolutionary studies on self-organization and cognitive studies on intelligence. Through this contextualization, the methodology on Living Labs and Stigmergic Prototyping can become more strictly defined. We then combine the methods into Convergent Action Research (CAR). To demonstrate and validate the CAR approach we refer to various real-life innovation examples.

Keywords: Living Labs, Stigmergic Prototyping, action research, self-organization, self-regulation, methodology, collective intelligence, design research, IT management.

1 Introduction

Innovation in technology has been a prime subject of attention for academics and practitioners alike, yet it is still fraught with unclarity and ineffectiveness. This is partly because of the complex and ambiguous nature of technology itself. Technology provides new ways to understand, control and steer the material world; the information and communication flows that technology embodies are adding a new dimension to reality that we don't fully grasp yet. This new dimension can be referred to as design. Design is an activity that aims to change reality, rather than an activity that merely describes something that exists. One of the reasons technology design has been so hard to grasp by management is that the development itself leads to novelty that changes the initial conditions. Indeed, technological innovation is a moving target. This is often expressed as technology mediation.

Philosophical studies have reasoned about the meaning of technology mediation. Clark (2004) claims that our symbiotic nature with technology makes us 'natural born cyborgs'. McLuhan & Fiore (1967) elaborated the idea that the medium is the message: the medium itself defines what kind of message can propagate through it. Ihde's (2009) contemporary philosophy around post-modern phenomenology – from now on simply called technoscience – makes technology mediation a central feature of study that builds on both McLuhan's and Clark's work (Van Den Eede 2011; Verbeek 2011). Still, technoscience lacks some key evolutionary insights. These posit that technology becomes an extension of evolution, more particularly in the sense of a new meta-system transition. Such meta-system transitions, e.g. the shift from single cell organism to multi-cell organisms, have been studied by Turchin (1977) and Smith et al. (1999). From an evolutionary point of view, meta-systems are always in process. It is in such a context that the Internet is considered as the emergence of a 'global brain' (Russell 1995; Heylighen 2001; Heylighen 2011).

This kind of philosophical discussion stands in strong contrast to the frameworks of practitioners of technology who are less concerned about the meaning of, and more interested in the means to, design and manage technology. Lewin (1946) introduced the term Action Research as "a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action". Next to Action Research, which became a rather dispersed discipline, Simon's (1947) problem-solving theories grew into a study of the artificial Simon (1969), which can be considered the origin of Design Science.

The term Design Science is only recently found in Information Systems literature. March & Smith (1995) denote the term to create a dichotomy between world-knowledge and useful-knowledge and construct a Design Science Research method. Design Science Research would get more developed in the next years (Aken 2004; Hevner et al. 2004). While authors such as Järvinen (2007) have claimed that Action Research and Design Science Research are similar, scholars such as Iivari & Venable (2009) argue there are clear distinctions. The argument is that Action Research basically refers to test-in-practice methods, while some Design Science Research applies to artefacts that cannot be tested that way, e.g. medical equipment. Sein et al. (2011) propose a new method that would combine features of both Action Research and Design Science Research, called Action Design Research. Action Design Research can be considered as a first attempt to develop a methodology to deal with designing novelty, which is the overlapping niche of both methods.

The gap between the 'philosophers' and the 'practitioners' mentioned above has been so broad that one hardly finds cross-references. Recent progress from the practitioner side helps reducing the gap. In particular, this paper posits that the 'Living Lab' line of work bridges the gap with evolutionary insights, while the scholars dealing with 'Stigmergic Prototyping' bridge the gap with cognitive insights. Living Labs refer to real-life testing and experimenting platforms to support user-driven innovation. Stigmergic Prototyping refers to prototyping by indirect, spontaneous interaction, and the learning process around it (Dejonghe et al. 2011). While no literature exists that systematically combines both concepts, they seem to allow, if taken together, a more holistic approach to, and understanding of, technology design. This paper tries to further reduce the aforementioned gap by making this combination and reinforcing the focus on development methodologies. In this process, it becomes necessary to more strictly define Living Labs and Stigmergic Prototyping, which could help practitioners too. The argumentation in this paper will also allow us to extend the Action Design Research to what shall be called Convergent Action Research (CAR). A first validation of our concepts was attempted by applying these novelty research principles to the challenge of self-regulating education via computer mediation. By means of preliminary conclusion, we position these methodologies (Living Labs, Stigmergic Prototyping and CAR) vis-à-vis one another.

2 Bootstrapping Microworlds by Vicarious Selection

For several decades, technological innovation has been accelerating. Over the years, various approaches have been put forward and applied to stimulate and guide innovation. All of these approaches are faced with two major dichotomies, which are strengthened by the particular characteristics of technology, and which give rise to a number of paradoxes that deeply affect the innovation process. One dichotomy deals with a focus on the artefact that actuates innovation (or technology), versus a focus on the environment (or ecosystem) in which innovations are necessarily embedded. The second, related dichotomy refers to conscious, goal-oriented innovation activities versus spontaneous, non-directed processes. The question then becomes how to combine non-directed development in a directed context.

Action Research, Design Science Research and Action Design Research all offer conceptual as well as methodological frameworks with the aim to describe, as well as prescribe, (parts of) the innovation process. Such methods are about a guided emergence that focuses on directing the development process, even if little attention is offered to the development environment, which is essential for spontaneously emerging interaction and self-organization.

The tricky part about innovation approaches is to capture something that is always to an extent happening spontaneously. Random and blind variation can spontaneously lead to constructive development, as both evolution theory (natural selection) and the history of technology development clearly demonstrate. Evolution had a 'Microworld' to produce major change. For example, the famous experiment to mimic the "primary soup" – the expected condition of the earth 4 billion years ago – demonstrated the origin of life (Miller 1965). Indeed, today Microworlds are often created in a laboratory to investigate a specific phenomenon. Such a Microworld is a directed context as it amplifies some features while damping others.

A Microworld as a directed context to examine non-directed development has in particular been applied in Artificial Intelligence experiments (Minsky 1988). In our terminology, a fundamental difference exists between a Microworld that allows spontaneous development and Living Labs that create guided emergence. Many animals have created Microworlds, which in evolutionary terms is called niche construction (Laland et al. 1996). Yet only humans have created Laboratories, even if some Laboratories have emerged spontaneously. How such complex elements can be created spontaneously requires us to understand how natural selection is extended with vicarious selection.

Campbell (1974) introduced vicarious selection as a special case of evolution where natural selection gets "substituted" by social selection. Vicarious selection is thus an intermediary selection process between spontaneous or natural selection and designed intelligent development. The best way to understand vicarious selection is by looking at the process of domestication. Compare domestication to taming. A tamed animal is captured in the wild, while a domesticated animal is bread in captivity, allowing a social selection to replace natural selection. Humans mostly do this, but some other animals are domesticators too, e.g. ants that farm fungi and milk aphids. Domestication of plants and animals require specific characteristics to be present beforehand, e.g. a zebra can't be domesticated. Diamond et al. (1998) have identified such characteristics and how they allowed some fertile niches to spinoff human development, like the Fertile Crescent.

Fertile niches were our first spontaneously emerging Microworlds, but many more can be recognized. What interests us for the current paper is the effect such Microworlds can have on intelligence. This can be demonstrated by observing psychological developments. Hebb (1947). observed how rats raised as pets with toys performed better on problem solving tests than rats raised in dull cages without toys, an effect which he called Environmental Enrichment. Environmental Enrichment is an effect of the Microworld and in turn leads to the Flynn effect. The Flynn effect refers to the observation that intelligence over generations increase (Flynn 2007). Biologically, our brain can't evolve at such speed, so the accelerated change has to be explained by Environmental Enrichment. To grasp how this is possible we need to examine non-directed development in a directed context, which starts by defining bootstrapping:

> *Two "things" A and B can be said to stand in a bootstrapping relationship if A is used to develop, support or improve B, while B is used to develop, support or improve A. In other words both B and A emerge into existence by prior, less defined "things".*

The most default bootstrap is between agents and their ecosystem. It leads to a 'game of fitness' so well known to students of evolution. Now that we elaborated how vicarious selection bootstraps Microworlds, and what effect this has on intelligence, the general context has been laid out in which we may position the practitioner approaches of Living Labs and Stigmergic Prototyping.

3 Essential Variables of Living Labs

As recently as 2006, the European Network of Living Labs was founded. It is currently the largest federation of Living Labs worldwide that counts just under 300 member organisations. Living Labs have thus quite rapidly become an entrenched part of the innovation landscape in many countries. Living Labs have been gaining a lot of traction as so-called user-driven open innovation platforms, but their relation to Action Research and Design Science is, while not trivial, underexplained. As practically driven and pragmatically operating organisations, Living Labs have been often diagnosed as lacking in theoretical and methodological rigour (Ballon et al. 2007).

Based on the above insights related to technoscience, evolution and cognition a more contextualized explanation of Living Labs can be given. In this sense, Living Labs are the next generation of laboratories that follow a more general trend in science from so-called Newtonian Science to Darwinian Science. The change from Newtonian Science, which is considered deterministic and predictable, to Darwinian Science, which is considered complex adaptive and self-organizing, has been a trend for several centuries (Prigogine & Stengers 1997). Classical Laboratories reduce complexity and self-organization to scientifically investigate very specific phenomena. A Living Lab typically does not reduce its Microworld to such limited parameters, but intentionally tries to bootstrap the vicarious selection of technology. This creates an ambiguous relation to the concept of Microworlds. It can be argued that the main difference between Microworlds and Living Labs is the presence of an agent that intentionally creates a guided emergence or vicarious selection.

As mentioned earlier, fertile niches were our first spontaneously emerging Microworlds, but the bootstrapping principle has shifted such Microworlds more and more to Living Labs. We can argue that Europe during the Industrial Revolution was, on a macroscopic level, more a Living Lab then a Microworld. Still on such a macroscopic level, intelligence is widely distributed. The other extreme is a classroom. In that context, the teacher creates the guided emergence, so only one 'intelligent agent' is in a sense needed. Most Living Labs are produced by an organization that contains a limited amount of 'intelligent agents' or regulators. In that case the division of labor is meant to improve guided emergence.

Two variables for Living Labs are hidden in this description. There is the degree of regulation (between spontaneous and controlled) and there is the level of scale (between micro and macro). In addition, a third variable for Living Labs can be observed, which refers to bootstrapping, and which we shall refers to as the ranking of novelty. To keep things simple, we suppose that each of these essential variables has three levels. For the degree of regulation these levels consist of peers, authority and system. With peers the regulation is almost spontaneous; an authority may have some control; while the system has full control. The three levels of scale are micro, regular and macro.

The three rankings of novelty are less evident. We will refer to emergence, bootstrap and intelligence. With simple guided emergence, bootstrapping is the effect of the development. However, Living Labs can also include bootstrapping into the development process itself, which is considered the 2nd novelty ranking. For example, for an emerging technology the social dimension can be explored by creating prototypes that mimic the expected outcome of the emerging technology. Such simple mock-up allows testing the social reaction during the technological development process. Profound novelty requires collective intelligence, which is our 3rd novelty ranking and will be associated to stigmergy prototyping in next chapter. Let us first demonstrate the levels of regulation and of scale found in present-day Living Labs.

Examples of different degrees of regulation, visible in Living Lab projects and initiatives, first of all include peer-based Living Labs. There, guidance is often limited to the provision of physical or virtual spaces that facilitate interaction between creative groups and individuals, yet without very specifically stated objectives, guidance or roadmaps, and with a focus on spontaneous processes of creativity and innovation. One example is the Manchester Digital Laboratory or MadLab, which describes itself as "a community space for people who want to do and make interesting stuff - a place for geeks, artists, designers, illustrators, hackers, tinkerers, innovators and idle dreamers; an autonomous R&D laboratory and a release valve for Manchester's creative communities" (http://madlab.org.uk). Secondly, there are Living Labs, which, despite their emphasis on user-driven open innovation, rely on a central authority that issues a number of rather specific guidelines and frameworks to steer the overall direction of innovation. One example is the European SmartIP pilot project, in which a.o. citizens in selected urban neighbourhoods are handed easy-to-use software tools and are being actively solicited by local social workers to invent, prioritise and develop their own neighbourhood applications (http://www.smart-ip.eu/). Finally, some Living Labs are systemic in the sense that all Living Lab activities directly relate to a central management entity. One example is the now defunct Kenniswijk Living Lab in Eindhoven, the Netherlands. This was a meticulously planned and fully managed implementation project, orchestrated by the national and regional public authorities, to use a Living Lab approach in order to develop and commercially roll out a large-scale Fibre-To-The-Home infrastructure as well as a range of related services. Interestingly, the lack of dynamism that surfaced after a number of months of operation, was attributed by several observers to the centrally managed approach, and eventually, a bottom-up, cooperative initiative in the nearby village of Nuenen had to be co-opted into the Kenniswijk project in order to save it from failure (see e.g. http://www.novay.nl/publicaties/lessons-learned-from-two-dutch-living-labs-freeband-and-kenniswijk/64764).

Related to the different degrees of scale, micro Living Labs comprise for example a classroom in which teachers and students may experiment with new educational tools and processes, or a small number of households where homecare technology is installed so that its real-life use may be observed (Van Den Eede 2011; Verbeek 2011). Regular-scale Living Labs include e.g. current 'smart cities' projects, in which several tens to up to a few thousands of users are involved in user-driven innovation processes (see e.g. http://www.epic-cities.eu/). Finally, macro Living Labs have a scale that is similar to the European Commission's Future Internet Public Private Partnership (FI-PPP), which aims at the European-wide implementation of a Future Internet technical platform and a number of 'generic enablers', which SMEs, non-profit organisations and citizens throughout Europe may use to test and develop new services related to a range of application domains, including energy, agriculture, transport, and media (www.fi-ppp.eu/).

4 From Stigmergic Prototyping back to Psychology

To move now towards the understanding the 3rd novelty ranking, requires us to examine intelligent agents and to close the gap between design science and cognitive studies. For this, we employ the concept of stigmergy (Theraulaz & Bonabeau 1999), which is an essential component in collective intelligence. Grassé (1959) introduced the concept while studying eusocial insects (e.g. termites, ants, bees). Stigmergy derives from the Greek words "stigma" (mark) and "ergon" (work), indicating that the decision-making is stimulated by the prior work. Stigmergy provides an elegant conceptualization of how the environment becomes part of the intelligence process, simply by the state of the environment. With termites, stigmergy takes place via dirt being dropped on a spot; with ants this happens with pheromones; and bees dance to pass the stigma. In a more recent work on self-organization, Heylighen (2006) examines stigmergic effects between humans and technology, which he illustrates with the case of Wikipedia. The idea of stigmergy in this context is then to have clear local tasks, but with a collective intelligence effect so that the whole is more then its parts. For example, search engines use the activities of their users to create good search results. Thus the intelligence gets delegated to a technological mediator, which is trained by the intelligent agents.

In current design research, authors such as Dejonghe et al. (2011) are explicitly using stigmergy for prototyping. This can be considered an extension of user-driven design. The same iterative loops exist as with any Action Research and the user still occupies a central position, but the game-changing effect of mediation is also considered. In this respect, prototypes gain more autonomy and evolve, via guided emergence, into products.

Mediation can come from technology, but also from people. The boundaries between stakeholders, developers and customers dissolve, as the bootstrapping process creates unforeseen change. It becomes more relevant to represent stakeholders, developers, customers and technology as agents that interact, with self-organization leading to coordination between them. In fact, such terminology reduces the gap with cognitive studies.

Stigmergic Prototyping is considered a way to deal with so-called wicked aspects. Wicked aspects occur when a problem can only be understood after the solution is found (Rittel & Webber 1973; Buchanan 1992). With wicked aspects, we seem to have reconnected with the original inspiration of Design Science, as both Lewin and Simon were inspired by cognitive psychology. In fact, both Living Labs and Stigmergic Prototyping imply to some extent a return to psychology studies. We already pointed to the relation between Living Labs and Enriched Environments. Another very important psychological effect relevant to Design Science is flow. Csikszentmihalyi (1988) introduced flow as a psychological state of mind where challenges and skills are both high and the subject (agent) gets into an optimal state of operation. While understanding the relation between flow and stigmergy is work in progress, it seems that stigmergy allows flow. Flow can be seen as a key element behind any good game or education and should be respected as an important design principle to build technology support for collective intelligence. Stigmergic Prototyping has in fact been used for teaching, more in particular for teaching industrial design to engineers. In this respect, Stigmergic Prototyping is used to create a flow with students to gain self-regulating education.

Stigmergic Prototyping has been a.o. applied by HoWest Industrial Design Center (IDC) as illustrated by their "Design for (every)one" project on inclusive design (http://designforeveryone.howest.be). Inclusive designs often deals with individual problems and their rehabilitation process. The group aims to gain more knowledge on the impact of assistive artefacts built around meaningful daily occupations. Disabled people and their caretakers become conscious actors in the design process, as well as more autonomous in maintenance of their own physical, mental and social well-being.

It is clear that stigmergic Prototyping asks for a new approach to prototyping. The prototype as an instrument of validation is not the sole focus anymore. The prototype becomes the changing mediator in the interaction, it needs to be designed using time as a design aspect, i.e. as a changing trace of interactions. The changing states should be observable and should be observed without influencing the interaction. This very fact requires a new kind of creativity from the designer, which is not required in more traditional research. Traces can be left in the prototyped artefact or in the environment, and these traces can be measured (e.g. through qualitative categorization, comparison with benchmarks, or counted if possible). The quality of the prototype will depend on what actions it makes observable.

It should not be a surprise that education is a fertile environment to validate Stigmergic Prototyping; after all, the roots of Design Science relate to problem-solving and this is key in education. Currently, much attention is going to serious gaming and so-called gamification for education. This fits a macroscopic level of evolution of Internet Innovation, after technology mediation for social activities (e.g. web 2.0) we now see technology mediation for problem solving emerging (e.g. Stack Overflow). It goes beyond the remit of this paper to examine this emerging macroevolution, but we can point out that such mediation has clear stigmergic design effects. This then makes it useful to elaborate on CAR and come back to the ranking of novelty.

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5 Convergent Action Research

For flow to become possible, challenges and skills need to be at the appropriate level. It is also at that moment when stigmergy becomes possible. Spool's (2005) intuitive design principle refers to the importance of the gap between current knowledge (the skills) and target knowledge (the challenge). Once current knowledge and target knowledge are similar, intuitive design is possible and stigmergic flow is the effect. The author gives the example of a kitchen. One's own kitchen is appropriate for a person, but other persons' kitchens seem counterintuitive to some degree. In order to render the environment more intuitive, more natural interfaces can be built. For example, a kitchen in which cupboards have glass doors so the user can see what is inside. In such types of cases, technology mediation solves part of the difficulty. The other way to reduce the gap is by providing training so that the user becomes familiar to the technology. The former solution reduces the required knowledge (the challenge); the latter improves the current knowledge (the skills). This process can be represented as a funnel (see figure 1.a). At the end of the funnel there is the Stigmergic Prototype. To move trough the funnel is to manage novelty. Closing the gap is precisely the focus of what we call Convergent Action Research (CAR), whereby 'convergent' is a reference to creating similarity between skills and challenges, as well as to convergent evolution.

Convergent evolution describes the acquisition of the same biological trait in unrelated lineages. While the convergence does not lead to exactly similar features and exceptions always exit, we do see a family resemblance emerging. For example, different species have created similar extensions in order to move trough a similar medium: wings for the air, fins for water and four legs for planes. While convergent evolution happens in Microworlds, CAR happens in Living Labs. For CAR, one needs agents that enable guided emergence, but there are several groups of agents that will be pursuing a same emerging medium. In this way, an ecosystem is bootstrapped and the family resemblance becomes observable. While the solution can't be known, a clear vision of the challenge would arise, which can lead to convergent development.

To reduce the required knowledge, the vision needs to become embodied, and so 'scaffolds' are needed. Instructional scaffold is a term used in educational studies (Wood et al. 1976), but also used by Clark (1998) to extend to embodied cognition. In CAR, artefacts help lower the challenge level, while scaffolds are used during training to improve the skill level, which results in Stigmergic Prototyping (left figure 1).

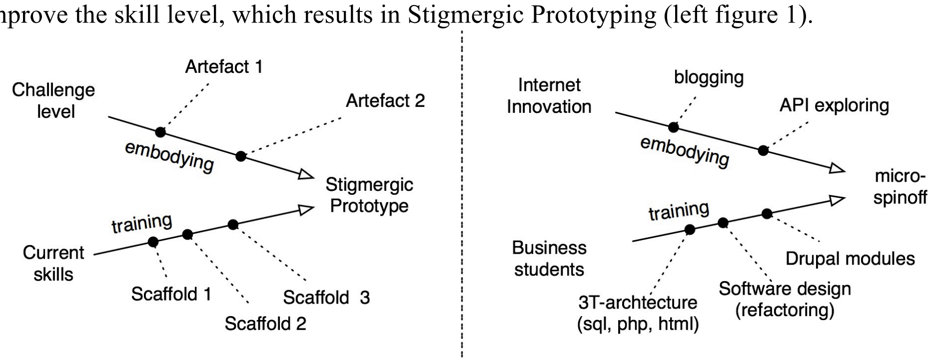

Figure 1 Left the schematic representation of CAR; right a particular case, were the concepts are retrofitted after experiencing the design development.

We have tested this CAR concept and method in the simplest Living Lab possible: a classroom. The agents were business students and the challenge was to understand Internet Innovation (right figure 1). We especially raised three questions:

1. How do you learn something that goes so fast your knowledge is obsolete by the time you learned it?
2. How can you build strategy if technology disrupts the target you're aiming for?
3. How do you create a scalable or sellable business (mostly a product) if the development has to be Free and Open Source Software (mostly a service)?

The first question refers to the problem of information overload and the acceleration of innovation. The second question addresses the problem of management in a complex adaptive environment. Both questions are generally relevant to Internet Innovation. The last question was specifically designed for the target audience of business students who needed to get a sense of how to manage software development, without it being the intention to turn them into programmers. The CAR-based solution consisted of a very particular training path, which was related to programming on the web and directed to integrate APIs. APIs are interfaces available online that can be used in software development to automate some service or application.

Simultaneously with this training in programming, the students had to embody their project idea, which resulted in peer evaluations (by blogging) and feedback from the teacher. Students would perform such peer evaluations, as this was part of the course criteria. A second artefact to embody the idea was to explore appropriate APIs on the Internet that could get integrated into their code. Combined with their improved programming skills, a Stigmergic Prototype could be created. Once this Stigmergic Prototype was developed, students were able to solve the first question and partly the second one. The prototype would evolve in such a way as to find a clear competitive advantage, which would solve the rest of the questions.

As each student was working under similar conditions, around the same questions, convergence could be clearly observed. In this case, all students started building a free service for which users would create stigmergic effects and that could turn this activity into a competitive advantage. Such platform effects can also be identified in current dominant services such as Google search or the iTunes store, yet in this Living Lab many small platforms emerged for niche markets and all of them were directed to harvesting collective intelligence via aggregation of stigmergic effects. Some student went on to try and build the business plan and acquire funding, and thus the concept of micro-spinoffs emerged as small business targeted to build software product using Open Source. This concept of micro-spinoffs represented a novelty that only emerged by family resemblance.

6 Conclusions

In conclusion, this paper has explored how Living Labs and Stigmergic Prototyping help to reduce the gap between Design Science and other studies related to technological innovation. While the concept and approaches of Living Labs reduces the gap with evolutionary studies on self-organization, the method of Stigmergic Prototyping reduces the gap with studies on collective intelligence. In the process we have identified three essential variables at play in Living Labs, i.e. degree of regulation, level of scale and novelty ranking. By describing and briefly analysing Stigmergic Prototyping we have explored the idea of novelty ranking in more depth and were able to introduce the Convergent Action Research (CAR) methodology. Based on this conceptual overview as well as on a practical example, we posit that CAR is useful when the distance between skills and challenges is too large, that CAR requires a Living Lab and that it leads to Stigmergic Prototyping.

Acknowledgement and disclaimer

Part of this research was funded by the European CIP project EPIC (CIP ICT PSP, Grant Agreement Number 270895). The responsibility for opinions expressed rests solely with the authors, and the publication does not constitute an endorsement by the European Union of the opinions expressed.

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