D3.2 INTEGRATIVE MODELLING (WORK AND ORGANIZATION)

Project Acronym:	DiDIY
Project Name	Digital Do It Yourself
Grant Agreement no.	644344
Start date of the project	01/01/2015
End date of the project	30/06/2017
Work Package producing the document	WP3 - Analysing how DiDIY is reshaping organization and work
WP Lead Partner	LIUC
Other Partner(s) involved	all
Deliverable identifier	D3.2
Deliverable lead beneficiary	MMU
Due date	M22 (October 2016)
Date of delivery	31/10/2016
Version	1.0
Author(s)	MMU, LIUC (Section 3)
License	Creative Commons Attribution ShareAlike 4.0
Classification	PUBLIC
Document Status	APPROVED

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 644344.

Executive summary

Deliverable D3.2, Integrative modelling (work and organization), introduces the simulation framework used to support the integrative modelling for the whole DiDIY Project and presents its first application to some topics related to WP3.

It starts with an introduction, discussing the role and aims of such simulation with respect to the kind of work in the rest of the Project. The next section briefly describes the modelling framework. Then there is a summary of relevant results and issues from WP3, followed by a plan for how these will be investigated using the framework.

Some of this material was mentioned in an Annex to the Knowledge Framework, i.e., D2.4, but this is the first time it has been officially reported. There is a substantial Annex – a more comprehensive specification of the Simulation Framework.

Revision history			
Version	**Date**	**Created / modified by**	**Comments**
0.0	15/10/16	MMU	First, incomplete draft.
0.1	24/10/16	MMU	Extensions and fixes.
0.2	25/10/16	MMU	Extensions and fixes.
0.3	26/10/16	MMU	Extensions and fixes.
0.4	27/10/16	MMU	First draft circulated to partners for comments.
0.5	28/10/16	LIUC	Extensions and fixes.
0.6	28/10/16	MMU	Extensions and fixes.
0.7	29/10/16	MMU	Extensions and fixes.
0.8	29/10/16	LIUC	Extensions and fixes.
1.0	31/10/16	LIUC	Approved version, submitted to the EC Participant Portal.

Table of Contents

1. Introduction: simulation vs. discursive accounts of phenomena

One of the innovative aspects of the DiDIY Project is the use of simulation modelling. This will complement the results of the various aspect-specific Work Packages by employing formal models linking the complex factors involved in the complex of phenomena we call "Digital Do It Yourself". The aim is to relate some of these different aspects and factors within dynamic and complex formal descriptions – agent-based simulations.

There is a subtle difference between discursive accounts of phenomena in natural language (such as concern most of the DiDIY Project) and formal models, such as the simulation models discussed here. This has ramifications for how they represent issues as well as how they are used – analogies and simulations are both (in the broadest sense) models of phenomena but they work in different ways.

Firstly, simulation is a formal technique, that is, it can be precisely specified and communicated without error. This means that it can be indefinitely passed between researchers for critique and piecewise improvement without ambiguities or confusion about its contents. A simulation is an artefact, similar to others made in DiDIY activities, its plans (the code) are shared among its own communities and re-used. This is unlike discursive accounts whose interpretation, and hence meaning, will change from individual to individual, which means that as the background ideas and values change so does the meaning of its analogies.

Secondly, although both discursive accounts and formal models can be used to theorise the connections between micro- and macro-phenomena, they do this in different ways (Figure 1 illustrates the move from narrative models to simulation models). Discursive accounts relate these in semantically rich but imprecise ways; they are free to bring together very different kinds of processes and properties under a single label (e.g., social capital). This allows a fluidity of expression that is ideal for group discussions and motivational stories, but the limitations of the human mind imply that discursive accounts cannot cope with situations that are too complicated to express or mentally follow (e.g., the details of hundreds of agents interacting) – it has to do this via abstraction. In contrast simulations map complex but precise possible ways they could relate (usually there is more than one-way).

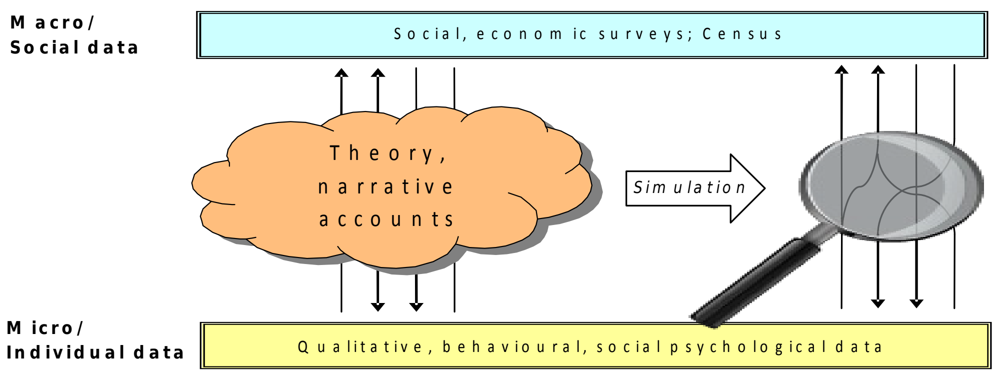

Figure 1 - Discursive approaches vs. simulation.

The consequence of these differences is that representing the issues as a simulation forces a number of distinctions that can be comfortably conflated or abstracted away in natural language. Thus, even the process of building a simulation can change the way one thinks about things, for example by:

- revealing gaps in our knowledge – bits of the process we had assumed we understood when in a natural language formulation, but when considered in detail it turned out that either there were several ways in which this process could occur, or we do not know how the process occurs;
- forcing us to assign a process or a property to a part of the system – for example whether an observed pattern is due to individual or collective mechanisms;
- forcing us to decide whether a phenomenon is basic, in the sense that it will assumed and built into the structure of a simulation, or emergent in that it is a (non-trivial) result of the simulation set-up and execution.

This difference in viewpoint – what might be called the simulation viewpoint – is not immediately apparent, but develops over time as one interacts with a simulation (either building and testing it or a series of discussions about a simulation). Thus, we expect that, as the DiDIY Project progresses, the simulation viewpoint will impact upon the Knowledge Framework, influencing its shape and content at the end of the Project.

Developing simulation models of complex social phenomena is a long-term project. Each simulation will inevitably include a lot of assumptions – there is simply not enough evidence and data around to specify a model based entirely on evidence. Thus each simulation is an assumption-relative complex hypothesis about how the different processes combine to produce the observed outcomes. However, the huge advantage of using a formal representation is that it can be safely passed between researchers so that the representation can be checked, critiqued and improved. It is “lineages” of formal models that can be developed over generations of researchers, “bootstrapping” useful knowledge about the phenomena (Edmonds 2010).

1.1 Agent-based simulation

There are many different types of simulation techniques. The approach we take here is that of “agent-based” simulation, a kind of computer simulation where every actor is represented by a different entity in the simulation, and the interactions between actors are represented by sequences of messages between those entities. This allows for a more detailed, common-sense representation of social phenomena, particularly those with a distributed, dynamic and complex nature (Macy, Willer 2002). This technique has been in existence for several decades now and is being applied to an increasing number of application areas (Edmonds, Meyer 2013).

This has a number of advantages over other techniques for our purposes here, specifically it allows for the representation of the following.

- *Actor heterogeneity* – Instead of having representative agents or even distributions the full diversity of actors can be represented as a set of agents, each with their own properties and behaviours (Squazzoni, Jager, Edmonds 2014).
- *Social embedding* – Socially embedded agents are ones where the particular network of interactions matter: behaviour is neither determined by society nor is it simply determined by an individual’s own interests (Granovetter 1985). One example of this is when the structure of social networks, over which the interaction occurs, is changing.

- *Complicated dynamics* – As with other kinds of simulation, such as cellular automata (Wolfram 2002), agent-based simulation can track the detail of extremely complex sets of interactions and objects. However, agent-based simulation take the degree of detail to another level by allowing the objects that are tracked to have complex internal (i.e., cognitive) processes as well as the interactions between the agents.
- *Context-dependent behaviour* – Whilst many formal techniques have to assume a generic model of behaviour, this is inadequate for modelling human behaviour in many cases because we can have very different behaviour in different kinds of situation (Edmonds 2015). Although such context-dependency is not so common in the field (or at least is left implicit), agent-based simulation has this capability.
- *A combination of top-down constraint and bottom-up emergence* – Whilst much social phenomena result form the (often complex) combination of the actions and beliefs of individuals in a bottom-up fashion, society does also constrain the actions of the individuals as the result of top-down decisions, but also in terms of the established norms. Agent-based simulation allows for both top-down and bottom-up processes (Conte et al. 2001).

2. A summary of the Simulation Framework: a model of making

2.1 Purpose

The specific purpose of this model is to provide the simulation infrastructure needed in order to describe the activity of making (we refer here to the subjects of the DiDIY Project by using “making”, “maker”, and “makerspace” for the sake of simplicity, leveraging on now popular terms: our more specific position on the relation between making and DiDIY is presented in “A Vocabulary of Digital Do It Yourself”, http://www.didiy.eu/vocabulary-of-digital-do-it-yourself”).

The model describes individuals using resources they can find in their environment plus other things that other individuals might sell or give them, to design, construct and deconstruct items, some of which will be of direct use to themselves, some of which they might sell or give to others and some of which might be used as a tool to help in these activities. It explicitly represents plans and complex objects as separate entities in the model – embedding the “Atoms – Bits” distinction highlighted within the DiDIY Project. This allows plans to be shared between agents which give the steps of how to make objects of use – either on a commercial or a free basis.

The Framework is intended as a basis upon which several specific models could be constructed, allowing the exploration of a variety of “what if” or counterfactual possibilities and thus giving a concrete but dynamic and complex instantiation of the issues and situations discussed within the DiDIY Project. The model can be then intended as a “bits” representation of the ideas discussed.

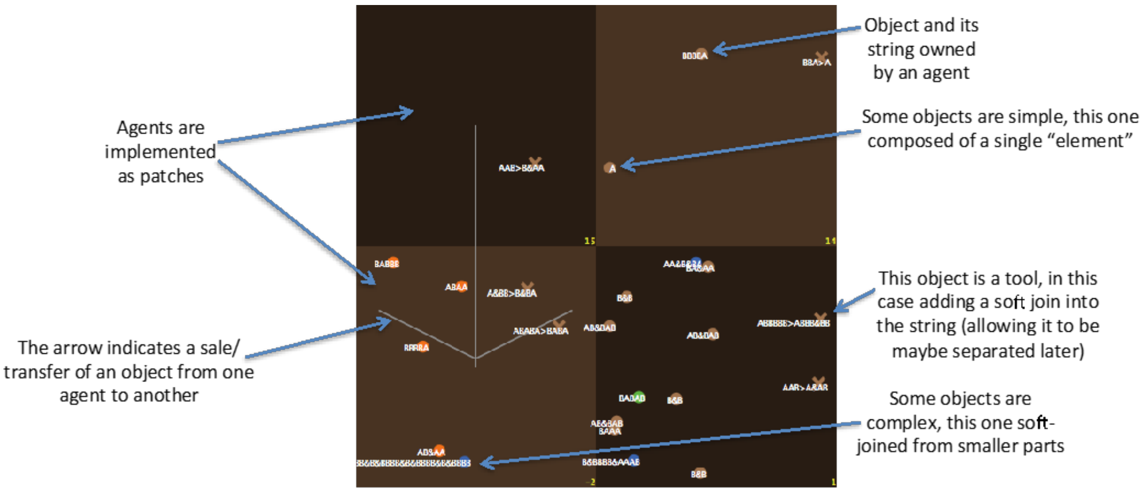

Figure 2 - A view of the model with agents, objects, and a sale.

2.2 Model components

There are three main kinds of entity in the model: agents, things and plans.

1. *Agents*. There are a fixed number of agents that do the making and decision making in the model. They own and hold things. They can (depending on the nature of the things) act upon these things to make new things. They can swap/trade things with any other agent. They also

hold in their memory a number of plans which they have either learnt themselves (through trial and error) or obtained from another agent.

2. *Things*. Things are individually represented and tracked within the model (from creation to destruction). They each have the nature of a 1 dimensional string of symbols, composed of a fixed number of "elements".
3. *Plans*. Agents remember sequences of actions they used to construct/deconstruct strings and the cost/benefit of the result as explicit plans. The ability to remember these plans allows agents to repeat successful plans and also allows the possibility of plans being shared/licensed between agents.

The world of 1D strings is sufficiently complex to make the process of working out which sequences of actions would result in which valuable strings a hard problem. Which strings are available in the environment and which strings have inherent "use" value are randomly determined at the start of the simulation. Which subset of strings is available to each agent and which subset can be redeemed by each agent can be varied, so as to be able to explore the impact on the heterogeneity of resource availability and agent's needs. This hardness is what makes plans valuable and so worth sharing.

In this model the potential for technological advancement is implicit in the affordances built into the making possibilities, a feature that is indeed built in the model. The ability to try actions and learn what seems to work, according to the motivations provided to the agents, is also built in. However the discovery of what works by the agents and what they discover is largely a matter of chance. The inequality in terms of value accumulated is something that emerged in the runs that were done. Similarly the kind of market that emerges in terms of buying and selling is a macro-level outcome from the model – the micro-level actions and learning of all the agents combine to produce it. Thus the model spans and distinguishes between (L1) mind processes, (L2) individual practice, and (L3) inter-individual phenomena. It does not touch upon (L4) the social dimension except via imagining the processes and results of the model as being within a wider society. This is usual for modelling activity, since it is ultimately a closed process and limited in its complexity.

A more complete description of the model, including its code, can be found in the Annex below.

2.3 First extension: sharing of plans

The structure of the above described model has been designed to make it easy to add a variety of processes, innovations, or affordances, for example the sharing or communicating of plans, different strategies for deciding what to do, the introduction of "1D printers" able to make any string (but only with certain elements), or different kinds of markets for agents to sell strings to each other.

Since sharing of knowledge and instructions – be it online or in person in a makerspace – is a core characteristic of DiDIY activities and the self-image of makers, we decided to include this in a first extension of the basic model. For this extended model we introduced a joint plan library, representing online contexts such as Instructables or Thingiverse. Agents may upload their plans to this joint library for other agents to use. An agent can also decide to download a plan from the joint library. At the moment, due to insufficient amount of empirical data about how and when makers actually decide to share one of their creations or make use of someone else's instructions, this is both done with a certain probability. Whenever an agent executes a downloaded plan successfully, s/he may decide to give it an up-vote. These up-votes may in turn influence the agents' decision about which plans to choose from the joint plan library.

To include these plan sharing activities into the behaviour of the agents, the main simulation loop was adapted as follows, with the new instructions in italics:

> Continually, each agent:
>
> *Considers downloading a plan from the "internet" (joint plan library)*
>
> Considers a number of plans (including the default random and downloaded ones) with a bias towards more valuable ones
>
> Until one works:
>
> Assess next plan to see if it would work
>
> If so, do plan! *And possibly up-vote it.*
>
> If new, compile and remember plan
>
> If have too many plans in memory, maybe forget one (with a bias towards the less valuable ones)
>
> *Considers uploading one of its own plans*

To assess the impact of plan sharing, we have conducted a number of simulation runs with both the basic model version and the extended model version. The following figures demonstrate some of the results of this comparison. The graph on the left hand side of each figure shows results for the basic model (without plan sharing), the graph on the right hand side the results for the extended model (with plan sharing). Each graph contains time series data from 10 simulation runs with the same model setup regarding the number of agents, elements, resources, target strings, etc. The difference in simulation runs is due to probabilistic effects within the model.

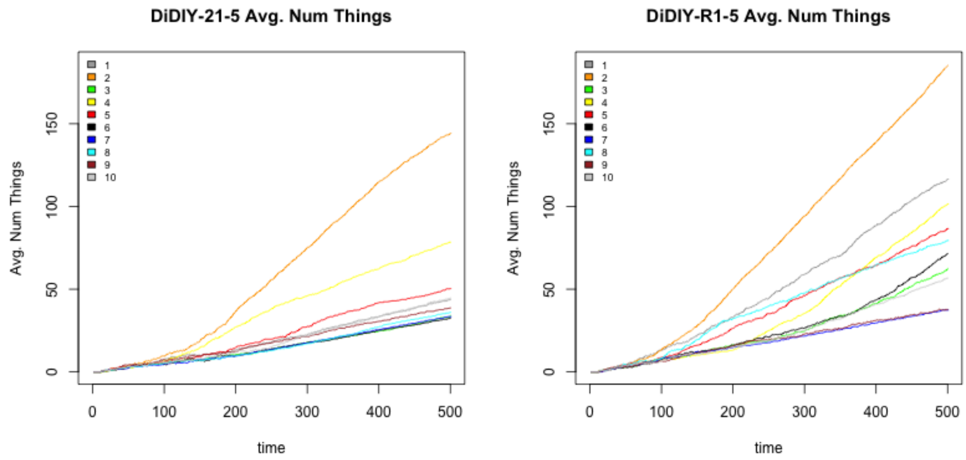

Figure 3 - The average number of things built in the model world, without (left) and with plan sharing (right).

As might be expected, plan sharing enables the agents to achieve building more things in total, at least in most of the simulation runs (see Figure 3). Once an agent discovers and uploads a successful plan, this is available to the other agents for download so they will not have to waste time and money in trying to develop this particular plan on their own. In accordance with this, the average wealth of the agents also increases with the sharing of plans (see Figure 4).

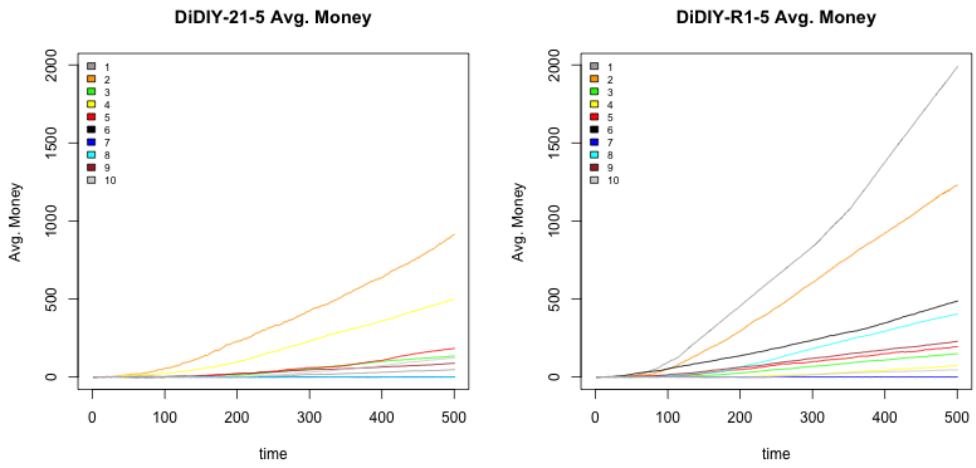

Figure 4 - The average wealth of the agents in the model world, without (left) and with plan sharing (right).

On the other hand, the number of distinct things constructed in the model world does not change with the introduction of a joint plan library, as can be seen in Figure 5. Agents do seem to rather stick with a set of established plans (either developed themselves or retrieved from the “internet”) to make things over and over again.

Contrary to expectations, the spread of the wealth amongst the agents is distinctly higher with plan sharing, i.e., there is a greater difference between “rich” and “poor” agents (see Figure 6). So instead of levelling the playing field by allowing other agents access to one’s own successful plans, the sharing in the model actually results in a more skewed society of makers.

It would be interesting to follow up on these first results, particularly with an investigation of their applicability to the real world.

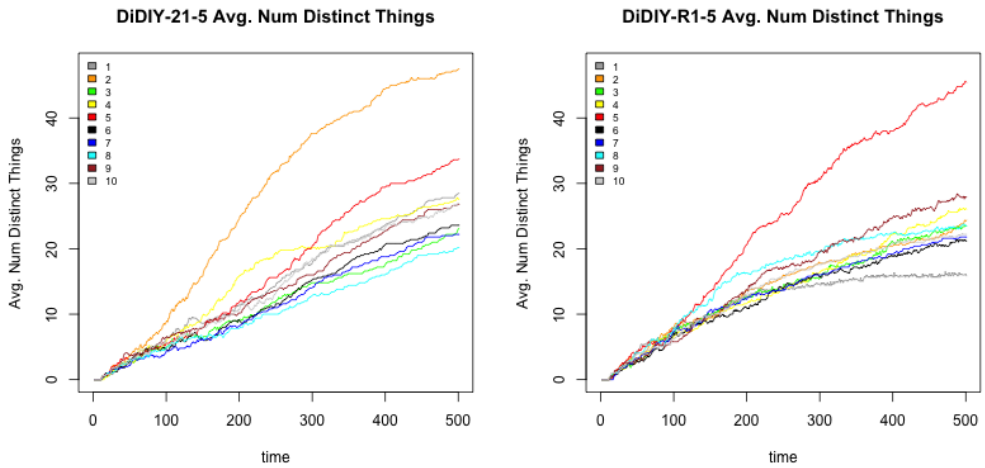

Figure 5 - The average number of distinct things built in the model world, without (left) and with plan sharing (right).

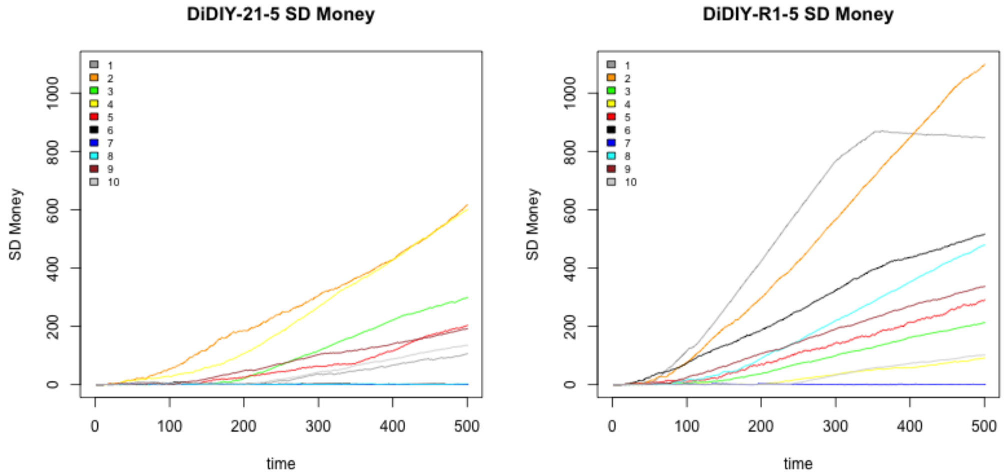

Figure 6 - The average spread of wealth in the model world, without (left) and with plan sharing (right).

3. Summary of Results from WP3

3.1 Introduction: Digital Do-It-Yourself in work and organizations

Digital Do It Yourself, among all its impacts and changes brought at both societal and organizational levels, is reshaping work and organizations due to the interactions between DiDIYers (and their aggregations) and their environment (Grover et al. 2012). The spread of DiDIY mindset and DiDIY activities among individuals acts as a strength influencing the evolution of the socio/economic/technological environments, together with other global phenomena, such as technological progress, globalization, migration (McKinsey 2015). By exploiting these trends – digital technologies and knowledge sharing – within certain community, activities previously carried out by experts can be now performed by DiDIYers, therefore asking for a reshaping of certain organizational roles (or, at a higher level of aggregation: certain organizational units, certain enterprises), workplace processes and structures.

In order to understand the skills characterizing DiDIYers, it is necessary to draw insights from the maker movement, that shares some fundamental elements with DiDIY. One of them is participation in a community, the main drivers being values (Dewey 1929), beliefs (Elby et al. 2001), and dispositions (Perkins et al. 2000). These drivers help in shaping the maker mindset: playful, asset- and growth-oriented, failure positive, and collaborative (Martin 2015; Peppler 2013). As investigated by Dougherty (2013) it is "experimental play" that has fostered the rise of new digital tools, an easier access to components and growth of online communities eventually culminated with the explosion of the maker movement (Martin 2015). Playful activities along with fun are at the heart of makers' activities that group and work together for "their pleasure in making and using their own inventions'' (Gershenfeld 2005). Persistence in the challenge of making (Vansteenkiste et al. 2004) as long as environmental conditions such as a playful learning environment encourage experimentation and create the basic conditions for the development of conceptual knowledge and adaptive expertise (Hatano et al. 1986). Another important element emerging from seminal papers is the freeness of makers to focus on doing the task or job they want. They can strengthen their expertise background as well as focus on something new to learn. The crucial topic is that makers focus on skills rather than abilities. As reported by Martin (2015), "making advocates a growth mindset, where, given effort and resources, anyone can learn the skills needed to complete any project they can imagine".

Learning environments that advocate a growth mindset encourage persistence, challenge seeking, and learning (Dweck 2000). Making environments typically give youth substantial say in what and how they make. Learning environments that support youth autonomy and control of their endeavours are more motivating, support engagement and persistence, identity development, and the growth of resourcefulness" (Azevedo 2011; Ryan et al. 2000). The free-choice nature of making emphasizes assets and the ability to learn over deficits – an orientation sometimes missing in school settings (Gutierrez et al. 2003). Therefore, makers do not experience failures of making as demoralizing (Soep 2014) but they understand that overcoming small obstacles is equally important. Petrich et al. (2013) state that "the process of becoming stuck and then unstuck is the heart of tinkering", and they find that such moments are often among the most salient. Sharing ideas, project, helping others, making and connecting characterize makers under the collaboration perspective. This mindset is probably the most important element when talking about makers and is shown both in online and in offline communities where makers group and collaborate to show their work (Kuznetsov et al. 2010).

3.1.1 DiDIY within Information Systems

A recent stream of research arising within the Information System domain deals with new business roles reshaped by the rise of new DIY technologies. The impact is at the employability level given that some of them need "a long education to develop new skills" (Davenport et al. 2015). Bernstein and Raman (2015) reported that "technological progress has decreased the demand for low-skilled information workers and increased it for highly skilled ones". The opportunity to have optimization of operations, easiness of design and flexibility in reconfiguring ecosystems is boosting the rise of digital manufacturing (D'Aveni 2015). A so-called "digital tsunami" is generated by new computing capabilities and rise in digital data generation thanks to the diffusion of disruptive technologies such as additive manufacturing, autonomous robots, data analytics tools, and industrial Internet of Things (IoT). "Digital technologies are transforming manufacturing value chain, from research and development, supply chain, and factory operations to marketing, sales, and service" (McKinsey 2015). Eventually, the large-scale availability of fast and pervasive internet connection is transforming the information flow inside and outside firm boundaries. Together with design, it is the production that is facing one of the biggest disruptive changes: manufacturers will perform better if close to the customers and therefore more feasible and localized. At the strategic level of an organization, decisions will be tightly coupled with operational ones as long as there will be a need for real-time decisions (D'Aveni 2013). Summarizing all the relevant changes presented, digital technologies are helping manufacturing firms to connect physical assets, thus unleashing a flow of digital data between different departments. Data digitally generated at production level can be accessible throughout the overall organization thanks to a shared and cloud-based infrastructure. Sensors, distributed inside manufacturing lines, are collecting data from the field and populating online database where this "big data" is analysed in real-time in order to take corrective actions. Lastly, managers and workers are facing a steady introduction of digital technologies (both hardware and software) in their daily activities that put them in a condition to digitally advance their skills.

From the literature review carried out, the following research questions, and related sub-questions, are arising.

1. How will the work of a worker in a manufacturing firm be reshaped due to the influence of DiDIY (Morris et al. 2010)?

   a. How will the work of a worker in a manufacturing firm change in relation with the evolution of other organizational roles in her firm (Zhang et al. 2013)?

2. How makers' characteristics (both personal and environmental) can be translated into an organizational context (Martin 2015; Peppler 2013)?
3. How do these characteristics favour a positive result?

   a. Do digital technologies favour DiDIYers (such as empowering people)? If so, in which situations? If not, is technology used for tasks automation only?

3.2 Research design

Previous sections aimed at highlighting which are the relevant elements that characterize a maker in terms of her/his skills, activities, technologies, and knowledge sharing mechanisms. This approach has been carried out with the aim to transpose it to traditional organizational settings and link it to the phenomenon of Digital Do It Yourself that has been described above. An important difference between makers' aggregations and DiDIYers within organizations can be related to the freeness of makers to act independently from any rule of law that can regulate, on the opposite, a traditional organizational setting. Moreover, any organization has specific mechanism of incentives and rewards for its workers and this can drive their motivation to perform better. Eventually, we believe that makers connect on a voluntary basis and are driven by grassroots passion to build and innovate using digital technologies. On the opposite, DiDIYers in organization are using digital technologies, introduced by the top management as an outcome of an overall firm strategy, to perform better (performance can be evaluated among different dimension that encompass financial, operational as long as organizational improvements).

The job transformation, or most in general business process transformation, deriving from the introduction of digital technologies is at the core of the Digital Do It Yourself phenomenon. We believe that makers and therefore DiDIYers can be characterized along two main dimensions: personal characteristics and environment characteristics. Autonomy and job attitude of the makers have to be adapted within the organization to favour a playful context similar to what happens inside offline makers' environments (e.g., makerspaces), where people can meet and learn one from the other. The playful context is surely relevant as a characterizing property of makers' aggregations and we believe that it can be replicated within an organization as a way to make workers participate more proactively to the processes. The framework aims at connecting these two main dimensions (personal and environmental) with the aim to define DiDIYers and empirically investigate them within organizational contexts. As previously mentioned, we aim at identifying the characterizing traits of a DiDIYer in an organization. To do so we, first, presents makers' relevant attributes and then we draw on potential attributes pertaining to DiDIYers acting within a traditional (i.e., SME or multinational) organizational setting.

3.2.1 Personal characteristics

- *Job attitude* – Workers usually have a production plan to follow and do not focus on the job they want. On the other hand, makers are free to focus on the task or job they like. This calls for a growth mindset, where, given effort and resources, anyone can learn the skills needed to complete any project they can imagine. In this light, digital technologies impact on the job allocation by granting a certain degree of flexibility (i.e., anticipation or delay of specific tasks) that can empower workers in prioritizing jobs according to their job saturation. The question to be addressed with the empirical investigation is: "how personal attitudes and motivations can be fostered in the working environment building on the case/experience of the makers generating innovation?" (Martin 2015).
- *Autonomy* – Within organizational settings usually most of the workers respond to a specific and fixed organizational structure. Making environments, instead, are typically characterized by autonomy and control of endeavours that create more motivation, support engagement and persistence, identity development, and growth of resourcefulness. We believe that digital technologies will allow coordinators of specific functional areas to be flexible in their activities and prioritize or postpone specific tasks (i.e., taking strategic decisions although being operative people). The question to be addressed with the empirical investigation is: "in

which context or tasks the availability of higher levels of autonomy may increase employees' commitment, creativity and innovation?” (Martin 2015).

- *Failure positive* – Workers in traditional organizations that fail to compute a task may have negative feedbacks from their superiors. Yet, within the maker mindset, failure is celebrated. Failure in making circles is seen as a productive possibility to better understand the structures and constraints of problems, so that they can learn better and try again. We believe that this mindset will allow improvements in the process of the organization (i.e., operative people learn better or faster methods to accomplish a task). The question to be addressed with the empirical investigation is: “how the process of facing and adapting to multiple sticking points may be important to the development of adaptive expertise?” (Martin 2015).
- *Multidisciplinary* – In traditional organizations workers have a task and they have to complete it more efficiently as possible, on the basis of their specialization. The maker movement welcomes all types of making. Typical interests enjoyed by the maker culture include engineering-oriented pursuits such as electronics, robotics, 3D printing, and the use of CNC tools, as well as more traditional activities such as metalworking, woodworking, and, mainly, its predecessor, the traditional arts and crafts. We believe that this characteristic could be beneficial in the organization in terms of motivation and new skills gained through interaction among others. The question to be addressed with the empirical investigation is: “how the collaboration between experts in a task and other workers is needed to help build bridges between the tacit knowledge cultivated through the act of doing and the explicit and abstracted formalisms valued in assessment?” (Peppler 2013).
- *Playfulness* – Workers in traditional organizations are characterized by an attitude of seriousness. Instead, the act of making is a playful one as makers are pushed to make by passion to discovery in a learning by doing way. Indeed, they are characterized by a critical engagement with technology often characterized by a sense of play around technological norms. We believe that this characteristic could bring new motivations for workers in organizations. The question to be addressed with the empirical investigation is: “how playfulness can be fostered within traditional organizational settings?” (Tanenbaum 2013).
- *Anti-consumerism behaviour* – Traditionally in organizations there is low environmental awareness and this is translated in waste of materials, energy, and money lastly. Makers, instead, are reported to support sustainability through an ethos of fixing and remaking. 3D printing and other technologies enable people to create the spare parts which will make something work again, or to develop innovative solutions to make things usable in new ways. These practices could be effective also in organizational context both with or without digital technologies. The question to be addressed with the empirical investigation is: “how a behaviour that pays attention to sustainability can be fostered in the working environment building on the experience of the makers’ serendipitous bricolage?” (Tanenbaum 2013).
- *Computational thinking* – In traditional organization when workers face a problem in completing a task they have to inform the supervisor that will handle it personally. Makers use instead computational thinking to overcome difficulties. Computational thinking aims at training people to think like computer scientists when facing a problem. This practice could be effective also in organizational contexts to spread problem solving and independence in the production line. The questions to be addressed with the empirical investigation are: “how

the introduction of computational thinking could be efficient in a production line environment?" and: "which computational tools could be helpful in doing this?" (Wing 2010; Rode 2015).

3.2.2 Environmental characteristics

- *Quality and availability of tools* – One of the most readily apparent features of the maker movement is the celebration and use of new and affordable digital tools. As these tools provide new ways of interacting with physical materials, they also offer new opportunities for learning so they are seen as enabler for the movement. Tools, like 3D printers or CNC mills, are all based on the same principle, using software to help guide the movements of a machine tool. These could have a huge impact in organizations and lead to a new industrial revolution. The question to be addressed with the empirical investigation is: "how these tools can improve productivity and pleasure to work of workers within the paradigm of Industry 4.0?" (Anderson 2012; Martin 2015).
- *Connected facilities* – Makers, rather than just be isolated, are stitched together in the larger maker movement through several events (like maker faires hosted locally, nationally, and internationally), periodical subscriptions like Make magazine, online communities like instructables.com or DIY.org, while maker adherents can connect through non-profit organizations like Maker Education. In this way knowledge is shared online and through social networks. The question to be addressed with the empirical investigation is: "how translating this characteristic (providing an online community within organization's facilities) in an organizational context could improve communication and productivity at plant levels?" (Peppler 2013).
- *Gamification* – The maker movement leverages on online communities that extend offline collaboration and provide spaces of collaboration and knowledge sharing. User participation in an online innovation community seems to be fostered by game elements that relate to the gamification concept. Gamification in an organizational context could be a disruptive innovation, leading sharing platforms to take place, with the aim to motivate people through the use of game elements and dynamics in nongame contexts. Game design elements refer to game design principles, game mechanics and game dynamics, storytelling and other aspects typically incorporated into games. The question to be addressed with the empirical investigation is: "how gamification mechanisms, if adopted, can improve the knowledge sharing, motivation and participation in an organization's online community?" (Hofferbert 2015).
- *Openness* – Closeness represents a typical trait of workers' behaviour. Vice versa, sharing ideas, projects, helping others, making and connecting, characterize makers under the collaboration perspective. The presence of digital technologies enabling information sharing may generate a higher degree of openness. The question to be addressed with the empirical investigation is: "when is it possible to introduce higher levels of openness and collaboration in the working environment to foster team building and innovation?" (Martin 2015).
- *Learning as social interaction* – In traditional organization social interaction is a trait of the breaks (e.g., lunch time). Vice versa the environment of the makers encourages people who work in a common domain, through their participation in the community, to share knowledge and experiences. Learning in each of these spaces is deeply embedded in the

experience of makers and an ongoing part of social interaction rather than a discrete activity. The question to be addressed with the empirical investigation is: "how it is possible, introducing in a traditional organizational context an ethos of learning within workmen as a social way of communication as the one of the community of practice (people who work in a common domain and through their participation in the community share knowledge and experiences), to expand skills, deepen knowledge, and tackle increasingly difficult problems?" (Sheridan et al. 2014).

In this study the impact of DiDIY-related technologies is under investigation on the activities carried out by a worker in such a way that his/her role will be critically reshaped. The focus is on analysing whether and how makers' characteristics, both individual and environmental, can generate an improvement in an organizational setting. We believe that, together with activities, competences will be reshaped accordingly. For example, a worker will not only need operation competences to execute specific tasks on a product but even strategic competences traditionally pertaining to managers. This big shift is resulting from the digital potential that nowadays is impacting on the automation of activities, especially in production (McKinsey 2015). The assumptions, at beginning of this study, were to draw insights from data collected, such as understanding how the work of a worker (e.g., a supervisor of job activities in a production cell) in production is reshaped by the introduction of recent and pervasive digital technologies (both hardware and software) in such a way that in addition to simply allocating jobs to workers (following a schedule defined by top managers) s/he will take strategic decisions on which are the most critical activities to be prioritized. Clearly, this will put her/him in a position to freely allocate – based on decision taken at production level (related to worker's competences, workstation saturation, ...) – the job to be carried out. Therefore, this action will carry a set of strategic skills that previously were not part of the skills portfolio pertaining to her/him. This flexibility, enabled by both software to support production such as PLM and new hardware to track items and grant visibility, is transforming the traditional production context.

3.3 Research method

Following Yin (2003), a case-study protocol was designed including the following sections: overview of the project (objectives and issues), field procedures, questions, guidance for the report. With respect to the current study, two criteria guided the choice of a case study research: the cost per subject and the potential for theory generation. In the empirical section of this research we used an exploratory case study whose aim is to let the emergence of changes in people and firms' performances induced by technologies. A multiple-case study approach (Yin 2003) was chosen for investigating the theoretical framework on how DiDIY is reshaping the work of a worker in a manufacturing firm. The approach resulted appropriate in order to answer to our research questions on which are the phenomena characterizing the reshaping of the work of a worker (Benbasat et al. 1987; Yin 2003). Future research will be, wherever possible, in the direction of a longitudinal study to facilitate comparisons and draw better insights.

According to Yin (2003), once firms have been identified, the selection of the correct data collection method depends on three factors:

- research method chosen;
- research topic;

- availability of data.

The unit of analysis chosen was “a worker in a manufacturing firm”. The case unit was analysed through the collection of primary and secondary data. Primary data sources were interviews, direct observation, and informal discussions. Secondary data sources were a set of documents of the firm that are produced as a consequence of the DiDIY transformation as long as web pages related to it. Before starting the collection of primary data (Darke et al. 1998), some preliminary background information was collected in order to help the interviewer during the data collection process. The preliminary information came from the web site of the firm and some supplementary information was given by the organizational interviewee. Together with a representative of each firm, the names and the positions of all the potential participants were identified and contacted for an interview (Darke et al. 1998). The interviews were semi-structured (Kerlinger 1964; Emory 1980). In order to operationalise the theoretical constructs and ground the findings, whenever possible, key representatives of a “worker” were interviewed. To increase homogeneity and comparability between the firms, a selection of them was made according to specific criteria such as B2B or B2C situation and similarity of firm size. Cases were chosen for enabling theoretical and literal replications (Yin 2003).

3.4 Data collection

A questionnaire was implemented as a guideline to perform the interviews, with the purpose to investigate how the work of a workman is reshaped by the influence of DiDIY. The questionnaire is composed of 4 sections, one in respect of each focal topic found in literature, and 25 questions. Since the research was highly exploratory, a pilot-case was followed by a multiple case study involving other firms selected appropriately according to the phenomenon object of the study (Yin 2003; Dubé, Paré 2003). To build a triangulation and to give rigour to the study other sources of evidence will be included: direct observations, historical archive records, physical artefacts. The quantitative data are collected directly on a copy of the interview guide by the interviewer, while the qualitative data produced by the interview are synthesized in a report, immediately after each interview.

3.4.1 Firms studied

The context of the empirical study is a set of manufacturing firms facing a digital transformation within their internal core processes: digitalization of physical assets thanks to the introduction of digital technologies transforming/reshaping how workers interact with the environment. This will affect their traditional activities that will, now, require a more managerial approach and not technical only. The reshape of work activities is considered fundamental and around this topic the data collection phase has been centred. The firms were selected taking into consideration their typical area of expertise, together with their natural disposition to the introduction of digital technologies, that act as enablers of DiDIY-based activities. Firms studied are located in Region Lombardia and are confidentially classified as Firm 1, Firm 2, Firm 3, Firm 4. The table below summarizes relevant information about these firms.

	FIRM 1	FIRM 2	FIRM 3	FIRM 4
industry	mechanical	mechanical	thermo-electro mechanic	textile
#employees	140	180	240	91
turnover ('15)	60-70 Mln. €	60-70 Mln. €	34 Mln. €	14 Mln. €
age of interviewee	n.a.	45	36	33
Business Unit of Interviewee	ICT and R&D	after sales	after sales	production

Table 1 - Firms overview.

3.5 Data analysis and findings

All interviews were tape-recorded and then transcribed. Durations of the interviews were between one hour and one hour and a half, producing an audio material of 305 minutes in total. In addition to the interviews secondary data, such as website pages and documentations, was collected. The data were encoded and structured into "projects" using the software NVivo 10 following a grounded theory approach (Strauss 1987; Glaser 1992) that aims at finding properties or links between data. The coding procedure was done as follows: first, in order to mitigate potential bias, a master student (first coder) who had not taken part in the interviews read and coded the interview transcripts by identifying text passages that included information about the constructs emerged from the literature. Following the coding of the first coder, another master student (second coder), likewise, coded the transcripts. The comparison of the two coding resulted above inter-coder reliability threshold defined by Holsti (1969). The two coders then examined the mismatched coding and agreed on a final coding matrix that was used for the data analysis.

3.5.1 Outcomes of the data collection: framework analysis

This Section discusses the main topics emerging from the interviews with regard to the framework previously presented. In this light, there is an attempt to discuss how the work of a workmen is reshaped according to the influence of DiDIY. Plus, by understanding what kind of activities can be DiDIY-related, there is an attempt to analyse how the work of a workman is changing with the evolution of other organizational roles in the firms' object of the study.

This Section aims at studying each case in relation with the framework used to define what a DiDIY activity is. The framework includes four main points that define DiDIY activities:

- a DiDIYer, a certain organizational role (or, at a higher level of aggregation: certain organizational units, certain enterprises),
- carries out on their own certain activities, activities previously carried out by experts (or specialized companies) (this aspect deals with the traditional notion of Do It Yourself),
- by exploiting certain digital technologies,
- possibly exploiting the knowledge sharing within a certain community (of individuals, of organizational entities) (this aspect deal with the innovative notion of Do It Together, where "together" refers to a community the DiDIYer belongs to).

The analysis of the framework is divided in two main parts, Within Case Analysis, developed to study each case separately, and Cross Case Analysis, that makes a comparative analysis of all cases.

Firm 1

Within Firm 1, we can recognize three potential cases of application of DiDIY.

In the first case the use of electronic documents allows salesmen – the candidate DiDIYers here – to access in real-time the information needed. In this way salesmen did not need any more to ask to production manager what machines are ready or to answer customers' needs; on the opposite they can do it by themselves using their own personal devices. Due to that new technology they do not change only how they worked before but they acquire also a new level of autonomy because they do not depend any more from production manager but they can develop activities without any experts' support. This one can be considered a DiDIY activity because three points of the framework are respected.

The second case is different from the previous one. Here the company decided to introduce a new system to automate the warehouse. While before were workers the people who decided what to pick up following a list of scheduled objects, now it is the system, guided by the ERP system, that calls for which parts are needed and shows where they are in the inventory. This new technology helps a lot all the workers because it increases the speed of the process and its efficiency, on the opposite it reduces their autonomy because they are now guided by the systems thus losing this minimum decisional power they had before. Also here we have a new technology that changes the way people work but, differently than before, this change is only a way to automate a process, to improve it but it did not have any relevant impact on workers. For that reason, it is not possible to consider this innovation a DiDIY activity.

The last case is about the trial process of the machines. While before workers needed to work only on one machine a time, now, thanks to the new automatic systems they can work on more than a single one because the program makes the work automatically. So also in this case it is possible to observe that, thanks to the new technology, workers' autonomy increases, although in a different way than the first case. Here workers gain freedom from the process and they become a little bit less workers and little more managers, supervisors of the whole process. The new implementation increases the speed of the process, because now it is possible to work in parallel on more machines, but it also changes significantly the way of work of employees, increasing their autonomy and their decisional power. For that reason, also this last innovation analysed can be considered a case of DiDIY activity.

Considering the framework introduced above, both the explanations about the innovation recognized as DiDIY activities refer to the last points of the framework. This because it is difficult to find in these two innovations the idea of Do It Together. But despite that, this idea is considered important in Firm 1, which studies innovations with their workers as an answer to specific needs or direct requests from workers themselves, who ask for new and more smart way to develop their activities. Firm 1 also gives a great importance to common moments of sharing, in which all the employees can express their opinions, like discussion during the coffee break where people can share knowledge and expertise, or informal/formal meetings. For Firm 1 Do It Together is then not only an option, but an actual culture.

Firm 2

Firm 2 implemented a new tool that allows workers to set a remote connection with a machine malfunctioning and with the aim to act controls and understand how to make an intervention. This new software is not a complete new tool because they had something similar before. The real innovation is the possibility to share the control of the machine with the responsible. In this way, Firm 2 workers can carry out the first intervention on the machine, understand the problem and also ask to the operator to make some activities that could help the investigation process. It is also possible for them to acquire information about problems could occurred during the life cycle of the machine, in order to know how to improve them or how to fix problems without the help of external experts.

This new digital innovation does not change radically the way people of the after sales department work, but allows them to improve the reputation of Firm 2 with customers and to become more and more independent from its suppliers for the assistance.

Contextualizing digital innovation implemented in Firm 2 within the contest of DiDIY, we can use the framework to identify DiDIY Activities: there is a DiDIYer, responsible of Firm 2 after sales department, who thanks to a software that allows a shared remote access to machines, changes the way in which he coordinates activities. Now he can collect more information about problems occurred and, sharing information with other functional roles, he can help to create more performing machines. This is also a special kind of increased autonomy: it is not the worker who has more autonomy, but it is all the company that can be more independent from its suppliers.

Considering the internal context, it is usual in Firm 2 to have formal and informal meetings in which to discuss about new products and share information, knowledge, and expertise. All this allows to create a sort of internal community in which working is easier and less stressing for each one. As it is evident, all the main points of the framework are respected so this activity can be considered as a core DiDIY activity.

Firm 3

Firm 3 introduced a new software that allows to have real time access information about all the machines spread around in all the construction sites furnished by the society. This new tool allows to know the exact location of all the machines without the necessity to ask for it to external people or to send someone to the construction site. At the same time, the tool lets the access to all the information and documentations concerning the single machines by remote and therefore to have them at disposal in case of control or necessity without have to carry all the papers. This digital innovation does not change radically the way how to develop activities: it only facilitates them thanks to a fast access to information.

Contextualizing this innovation in the contest of DiDIY, we can use the framework to identify DiDIY activities: there is a DiDIYer – the construction site assistant – who thanks to a new software can have an easier access to information and can develop his activities faster and easier. Now workers can avoid to ask someone to check where a specific machine is, but a worker does not really acquire new autonomy because although s/he can take some decisions on her/himself, for the most important ones s/he has to ask to a superior.

The interview shows that Firm 3 is a pleasant working context, in which communication and sharing of information are common between workers. As it is evident, not all the main points of the framework are respected so this activity can be considered a DiDIY activity.

Firm 4

Firm 4 developed a new software enabling workers to get complete and updated information in real time, always available on the printing machines and accessible to all stakeholders. Nowadays, the changes of printing production schedules can be handled by workers who interacts with production progress software, even providing data updating in real-time. All productions are recorded during the process, so in case of suddenly interruption of printing machines, workers of the following shift can have a complete view of situation and manage possible problems, avoiding to call colleagues or department heads and using paper sheets to share anomalies. Thanks to digital innovation applied to Firm 4, the projects and the printing production schedules are already saved by production progress software and, consequentially, set-up time of the machines and the number of errors made during printing of fabrics are drastically reduced to ensure an equal level of quality.

The production progress software allows an integrated data management; the information is available from the beginning until the end of production process. Due to the lack of flexibility of the process the autonomy of workers is not granted, but a great advantage is the speeding up of getting information. Furthermore, another advantage is using the time saved to improve the quality of the production process. Aiming at contextualizing the digital innovation implemented in Firm 4 within the contest of DiDIY, we can use the framework to identify DiDIY activities: there is a DiDIYer – the printing department head – who thanks to a software that manages the production progress changes the way in which he coordinates activities. Up today, he gives orders and checks prints without asking support of specific people therefore reducing the number of support requests to the production head and to customers. Having all necessary information in real time it allows to elaborate the data and take decisions that will be transmitted to the machine operators. Taking into account the knowledge sharing we report a scarcity of it between workers. It casually occurs only with workers in the same shift or among department heads. Both for security and process structural reasons the knowledge shared with other communities is totally absent (e.g., workers cannot access to internet).

Not all the four points of the framework are respected, so that this activity can be considered only as a DiDIY activity.

3.5.2 Summary of personal characteristics

- *Job attitude and autonomy* – A firm structure and its goals, after digital innovations, do not allow workers to focus on the task or job they want, unlike makers. Evidence showed that workers have a lack of flexibility because production processes are too strict. Due to the absence of flexibility in the process, autonomy of workers is not granted in all surveyed firms. Workers have been stuck in the tasks that have been assigned to them, also in order to avoid errors. Only department heads and directors have more decision making autonomy and flexibility given their position within the organizational structure.
- *Failure positive* – All surveyed firms have a positive opinion on failures: with the aim to work well and reduce the number of errors, failure is seen as way to learn from mistakes. On the other hand, firms' culture and behaviour of department heads or directors are not ready for that: a failure involves an economic damage, a delay in products delivery and a negative opinion of customers.
- *Multidisciplinary* – All interviewed firms think that the sharing of knowledge among people with different competences and with different roles may bring benefits both in terms of motivations and new acquired competences.

- *Playfulness* – The interviewed firm associate playfulness with the work environment and the sphere of relationships among people: the concept of playfulness should not be merely associated with the hedonistic concept of 'play with technology'. In fact, makers are characterized by a critical engagement with technology, where the sense of play is perceived together with the awareness of the properties (and thus of the constraints) of the technology.
- *Anti-consumerism behaviour* – No firms use specific digital technologies, such as 3D printers, to enable people to create the spare parts or to develop innovative solutions to make things usable in new ways. All surveyed firms are careful not to waste any resource, so to increase efficiency and reduce costs.
- *Computational thinking* – Problem solving skills are required for each firm object of the study: this is translated into greater decision making autonomy for department heads (while top management decision making is unlikely affected by DiDIY impact on workers) under the condition of an increased flexibility for the workers.

3.5.3 Summary of environmental characteristics

- *Quality and availability of tools* – The adoption of new software and new tools of communication has changed the way to work and to access the information: real time data, complete and more secure data. The information is available directly on machines, thanks to increasingly advanced sensors introduced at the plant level, and on the mobile devices such as tablets or smartphones.
- *Connected facilities* – No interviewees use specific communities: in this way knowledge is mainly shared within the firm, between colleagues. Sometimes internet or Google are used to make specific research necessary to solve a problem.
- *Gamification* – The concept of gamification is not present in any interviewed company: user participation in an online community does not exist. Game design principles, game mechanics and game dynamics are concepts far from reality.
- *Openness and learning as social interaction* – The presence of digital technologies enables information sharing within all surveyed firms; this leads to increase collaboration and experiences in sharing ideas, projects, helping others, making and connecting.

3.6 Research results

This Section aims at discussing the results emerged according to the research questions. The collected data have been coded and analysed using NVivo: this was helpful for defining the fundamental inputs and building answers to questions of research. At first, we try to answer the research questions of the study that are referred to personal and environmental characteristics showing how these characteristics can be translated into an organizational context. Afterwards we try to understand how the work of a worker in a manufacturing firm will be reshaped.

3.6.1 Discussion

Building our study from the skills characterizing a maker, and which among those skills can enable her/him to achieve superior performances, we reported that the available research on DIY can provide only a limited support. The results of the empirical analysis helped to define the state of fundamental elements constituting DiDIY and, therefore, to shape how the maker mindset can be translated into an organizational setting. In fact, an organizational chart and a corporate structure are close to rigidity and immobility thus favouring the diffusion of a sectorial mentality and the related creation of airtight behaviours. All this, means that workers tend to attain to relationships and communication channels formally mapped. Consequently, this can discourage the collaboration and knowledge sharing outside of organizational boundaries such as with other employees of other companies and workers with other skills. In the previous Section we were able to observe the absence, or however a different conception, of some of the characteristics we investigated such as job attitude, autonomy or connected facilities. For other characteristics it was difficult to find them within the firm object of the study, given that there was a limited knowledge or a lack of skills for them. Eventually, autonomy, job attitude, playfulness and multidisciplinary, for example, are personal features that need a radical change at firm level.

Taking into account the results emerged from the data analysis, we believe it is important to contextualize and analyse the three words emerged from NVivo frequency analysis: people, information and work. The aim is to interpolate these three elements with digital transformation that is in place in the firms today, in order to understand which are the conditions that favour the introduction of maker's characteristics in the business context. The technology can create a virtuous cycle for the firms and the people working for them: it would be too narrow to stop and observe that more and more human labour will be replaced by machines. In this digital innovations era, in fact, people are still at the centre of the process and they cannot be excluded from the ongoing transformation. Digital innovations are transforming processes and products ensuring more efficient activities. New tools and new software enable workers to get complete and updated information in real time, always available on machines and accessible to all stakeholders. Digital innovations allow an integrated data management allowing the information to spread from the beginning until the end of production process. In this changing context, a need is rising: a different organization of work, determined by a production that is changing becoming more and more flexible both in its activities and physical spaces. This different paradigm happens even in terms of industrial relationships and relationships between workers and enterprises. It is a new model where the growth is shared and it is responsibility of everyone, without any border between organization and workers. It is a model of spread benefits: the new process is more democratic because the company can produce behaviour for those ones are parts of its entourage, that does not include only its own employees. Workers should operate in environments with more diversity and less hierarchies, in which continuous updating and education take a central role. Companies have to organize connected environments, open to everybody, able to stimulate and to satisfy workers. People, as the firms, have to understand that there is a change in action: everyone has to take care of their employability with empowerment and responsibility.

To conclude, according to what said before, it is evident that the three words emerging from axial coding (people, information, and work) are key concepts around which a firm, that wants to remain competitive and catch the opportunities offered by digital revolution, has to work and to develop innovative strategies to acquire all the characteristics typical of maker movement.

3.6.2 Emerging profiles

With the aim to contextualize each case with the referenced framework we obtained three main profiles of DiDIYers, linked to personal characteristics and environmental context. We compare them with the aim to highlight differences and similarities.

The first profile is the worker from Firm 2. He is closer to a supervisor than to a worker. With the new technology this is truer and more valid than before. He increases his autonomy, having more decisional power, and flexibility because he can focus on the aspects of his activities he likes more. He contributes to achieve better results for all the company. All this is sustained by a pleasant work environment in which collaboration and sharing are key points of organization's culture.

A similar profile, but not equal, is the one of the worker from Firm 4. He is more close to a supervisor too, but differently from the previous type, he is less free. He has some decisional power but he is still stuck in the rigid organizational structure in place with the aim to avoid mistakes and problems. The environmental context is different too: in Firm 4 there is less collaboration and sharing than in Firm 2. That is due to a different work organization: in Firm 4 people work in shifts and it is difficult to find and create moments for sharing knowledge. Nevertheless, a less collaborative context, the company organizes and manages contests in which each worker can propose an idea to improve efficiency and efficacy of the process.

Last profile is the worker from Firm 3, where there is a really different situation than the two before. Here there is not any increase of freedom, the new software does not allow the worker to have more autonomy or to focus on the activities he likes more. He only has limited decisional power on the activities necessary to repair something, but for all the rest he still completely depends from his superior. The new software only impact on the speed of the process. Eventually even in this firm there is a collaborative environmental context but no real cases were provided from the interviewee.

4. Future development of the model with respect to WP3

Integrative simulation models can help investigate some of the research questions identified in WP3 and documented in the previous Section. While these cannot definitively answer the questions for any real-life scenario, they can aid investigation into how different factors may interact and may aid in the refinement of the research questions and suggest new hypotheses for investigation. Such a model may also play a role in aiding the development of the final conceptual framework by providing concrete examples where the concepts can be precisely illustrated.

The prototype model provides a base for the relatively rapid experimentation of a number of different scenarios. However, in practice only a few of these will be able to be explored by the end of the Project. For this reason it is important that we carefully target future modelling efforts. These directions should be:

- justified by coming out of the results, or at least conceptual developments of the Project;
- be feasible in terms of modelling – representing a compromise between not being too abstract but respecting the limitations of the data.

A central question arising from the research pertaining to WP3 is: "how the work of a worker in a manufacturing firm will be reshaped due to the influence of DiDIY". As can be seen from the case studies of the four firms, DiDIY in this context allows workers to overcome the traditionally strict organisational hierarchies by having direct access to relevant information, e.g., the status of machines via real-time information systems implemented in the factory. A simulation model of this general scenario would need to represent a (more or less abstract) manufacturing firm with supervisors, workers, machines and tasks to be performed. Its purpose would be to capture the change in workflow that might happen due to the introduction of freely available information about which machines are in use and which tasks need to be finished within which deadlines. Experiments with such a model could then be run to investigate particular aspects of the central research question, including the following:

- if we allow the workers autonomy in the decisions concerning the order in which they want to perform outstanding tasks, does this improve the effectiveness of the production process?
- would supervisors become superfluous since workers are self-organising their work?
- what is the impact on the manufacturing unit as a whole – is it more productive or differently productive?

The original simulation framework, described in Section 2, distinguishes between agents (makers, modelled as patches), things (including rudimentary tools, represented as strings), and plans (instructions on how to make particular things by applying one or more of the available actions or tools). To be able to model scenarios relating to workers in a manufacturing environment we will develop this simulation framework further by shifting the focus from the process of making (i.e., agents finding ways to construct things) to the process of decision making (i.e., agents deciding when to do what).

We will use the following mapping of existing model elements to scenario elements:

Agents	→	workers and supervisors
Things	→	tasks (products to be produced)
Tools	→	machines
Plans	→	list of necessary operations (machines) for completing a task

The way tools and actions are realised in the model framework so far will have to be expanded to allow for a suitable representation of machines. In contrast to the original model of making, plans will usually be pre-existing instead of being discovered by the agents through trial and error or learning. Another extension of the model framework will be the explicit representation of the time it takes to perform particular actions. This is necessary to be able to determine when machines are free and if tasks can be completed within certain deadlines.

In order to investigate the impact an accessible, real-time information system would have on the organisation of work, we will compare a version of the model where workers will have to ask their supervisor for information about the next task to perform with a model version where all workers have access to the necessary information about machines and tasks so that they can decide themselves which of the outstanding tasks to work on next.

Once this core extension of the Simulation Framework is developed and sufficiently tested, we could look into adapting it further to accommodate a selection of the personal and environmental characteristics of DiDIYers as identified in WP3. The model described above already incorporates the first of the personal characteristics ("job attitude and autonomy"). By allowing agents to communicate about their decision making, e.g., sharing efficient solutions for commonly occurring configurations of tasks or which machine to avoid for the completion of a particular type of task, we could include characteristics such as "multidisciplinarity", "failure positive" or "openness and learning as social interactions".

5. References

Anderson, C. (2012). Makers: The New Industrial Revolution. Crown Publishing Group.

Assenza, P. (2015). If You Build It Will They Come? The Influence of Spatial Configuration on Social and Cognitive Functioning and Knowledge Spillover in Entrepreneurial Co-Working and Hacker Spaces. Journal of Management Policy and Practice 16.3: 35.

Attia, E.A., Duquenne, P., Le-Lann, J.M. (2014). Considering skills evolutions in multi-skilled workforce allocation with flexible working hours. International Journal of Production Research, 52(15), 4548-4573.

Cannella, A.A., McFadyen, M.A. (2013). Changing the exchange the dynamics of knowledge worker ego networks. Journal of Management: 0149206313511114.

Conte, R., Edmonds, B., Moss, S., Sawyer, R. K. (2001). Sociology and Social Theory in Agent Based Social Simulation: A Symposium. Computational and Mathematical Organization Theory, 7(3):183-205.

Dobbs, R., Manyika, J., Woetzel, J. (2015). The four global forces breaking all the trends. Book excerpt from No Ordinary Disruption, Ed. Public Affairs 2015. http://www.mckinsey.com/insights/strategy/The_four_global_forces_breaking_all_the_trends.

Edmonds, B. (2010). Bootstrapping Knowledge about Social Phenomena Using Simulation Models. Journal of Artificial Societies and Social Simulation, 13(1):8. http://jasss.soc.surrey.ac.uk/13/1/8.html.

Edmonds, B. (2015). Contextual Cognition in Social Simulation. In Brazillon, P., & Gonzalez, A. J. (eds.) Context in Computing - A Cross-Disciplinary Approach for Modeling the Real World. Springer, 273-290.

Edmonds, B., Meyer, R. (2013). Simulating Social Complexity - a handbook. Springer.

Gastaldi, Luca, et al. (2014). Smart working: rethinking work practices to leverage employees' innovation potential. 15th International CINet Conference, Operating Innovation - Innovating Operations, At Budapest, Hungary.

General Assembly + Burning Glass Technologies (2015). Blurring Lines: how Business and Technology Skills Are Merging to Create High Opportunity Hybrid Jobs. http://burning-glass.com/research/hybrid-jobs.

Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. American Journal of Sociology, 91(3):481-510.

Irfan, A. (2015). Antecedents and Outcomes of Work-life Balance. The International Journal of Business & Management 3.1.

Kane G.C. (2015). The Workplace of the Future. MIT Sloan Management Review, June.

Kinnie, N., Swart, J. (2012). Committed to whom? Professional knowledge worker commitment in cross-boundary organisations. Human Resource Management Journal, 22(1), 21-38.

Krishnakumar, S., Juin C. (2014). Understanding the Nuances of Work-Life Balance. Review of HRM 3: 81.

Lacity M.C., Willcocks, L. (2015). What Knowledge Workers Stand to Gain from Automation. Harvard Business review, June.

Lake, A. (2013) Smart Flexibility: Moving Smart and flexible Working from Theory to Practice. Leadership & Organization Development Journal, 34.6: 588-589.

Lee, J. (2013). Cross-disciplinary knowledge: desperate call from business enterprises in coming smart working era. Technological and Economic Development of Economy 19.sup1: S285-S303.

Macy, M. W., & Willer, R. (2002). From factors to actors: Computational sociology and agent-based modeling. Annual review of sociology, 143-166.

Meier, J., Crocker, M. (2010). Generation Y in the workforce: Managerial challenges. The Journal of Human Resource and Adult Learning, 6(1), 68.

Mikulecký, P. (2008). Towards smart working environments. IADIS Conference.

Moon, M. (2009). Knowledge worker productivity. Journal of Digital Asset Management 5.4: 178-180.

Morganson, V.J., Major, D. A., Oborn, K. L., Verive, J. M., Heelan, M. P. (2010). Comparing telework locations and traditional work arrangements: Differences in work-life balance support, job satisfaction, and inclusion. Journal of Managerial Psychology, 25(6), 578-595.

Niles, J.M. (1998). Teleworking: Strategies for Managing the Virtual Workforce., New York, Wiley.

Noel, A. (1989). Strategic cores and magnificent obsessions: Discovering strategy formation through daily activities of CEOs. Strategic management journal 10.S1: 33-49.

Osservatorio Smart Working (2016). Nuovi modi di lavorare: una panoramica sullo smart working (in Italian: “New ways of working: overview on smart working). Research Report. Politecnico di Milano. April.

Petrick, I.J., Simpson, T.W. (2013). 3D printing disrupts manufacturing: how economies of one create new rules of competition. Research-Technology Management 56.6: 12-16.

Quinones, P.A. (2014). Cultivating practice & shepherding technology use: supporting appropriation among unanticipated users. Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing.

Schneckenberg, D. (2009). Web 2.0 and the empowerment of the knowledge worker. Journal of knowledge management 13.6: 509-520.

Squazzoni, F., Jager, W., Edmonds, B. (2014). Social Simulation in the Social Sciences: A Brief Overview. Social Science Computer Review, 32(3):279-294.

Strategic Policy Forum on Digital Entrepreneurship (2016). Accelerating the digital transformation of European industry and enterprises. March.

Tanenbaum, J., Williams, A. M., Dejardins, A., Tanenbaum, K. (2013). Democratizing Technology: Pleasure, Utility and Expressiveness in DIY and Maker Practice. Conference CHI 2013: Changing Perspectives. Paris. France. pp. 2603-2612.

Wang, J., Verma, A. (2012). Explaining organizational responsiveness to work-life balance issues: The role of business strategy and high-performance work systems. Human Resource Management, 51(3), 407-432.

Williams, A., Nadeau, B. (2014). Manufacturing for makers: from prototype to product. Interactions, 21, 6, pp. 64-67.

Wolfram, S. (2002). A new kind of science. Wolfram Research.

World Economic Forum (2016). The future of jobs: employment, skills and workforce strategy for the fourth industrial revolution. World Economic Forum, Geneva, Switzerland.

Wu, F., & Zhang, X. (2014). Employees' positions in virtual working community and their job performances: a social network analysis. Human Resource Development International, 17(2), 231-242.

Xiao-dong, J.I., Cong-Zhen, A.N. (2010). Working Smart, Working Hard or Social Network. The Determinants of Salespersons' Performance in Direct Selling Firm. School of IBA, Shanghai University Press.

6. Annex – A specification of the Simulation Framework

This code of this model and this documentation are freely available (Edmonds 2016a). Netlogo to run it is freely available at (Wilensky 1999) and the necessary extensions at (Netlogo Extensions). Some slides introducing the model (Edmonds 2016b).

6.1 Entities

There are three main kinds of entity in the model: agents, things and plans:

1. *Agents*. There are a fixed number of agents that do the making and decision making in the model. These are individually represented as "patches" in the model. They own and hold things. They can (depending on the nature of the things) act upon these things to make new things. At the moment their position is not important and they can swap/trade things with any other agent. They also hold in their mind a number of plans which they have either learnt themselves (through trial and error) or obtained form another agent.
2. *Things*. Things are individually represented and tracked within the model (from creation to destruction). They each have the nature of a 1D string of symbols, composed of a fixed number of "elements" (the letters "A", "B" etc. depending on the parameter which determines the number of elements) and the two symbols "&" and ">". "&" indicates a soft join, that is a join that an agent can make (or break) without a specific tool. ">" indicates that the item can also be used as a tool, that is it can be used to "transform" the string on the left of the ">" into the one on the right in another string.
3. *Plans*. Agents remember sequences of actions they used to construct/deconstruct strings and the cost/benefit of the result as explicit plans. These plans are a tree structure of actions and the strings that resulted. The ability to remember these plans allows agents to repeat successful plans and also allows the possibility of plans being shared/licensed between agents.

6.1.1 Process overview, scheduling

The most important process is that of agents picking one of their plans (some of which are default, "try something random", plans) and then doing its steps. The cost/value of the result of doing these plans are remembered (basically value – costs in making the object) so that later plans that are better can be preferentially chosen in this process. Thus this combines some trial-and-error with developing a focus on plans that worked better. The main process is outlined below.

Each tick the following happens:

1. Some variables and links are cleared
2. **Main loop**. Each agent does the following in a random order of agents:
    - 2.1. Initialise variables, compile a choice list to speed up plan choice
    - 2.2. *Until* a plan succeeds or a given number of attempts have been exhausted:
        - 2.2.1. Choose a target string from plan memory, find a (given) number of plans from the memory that would result in this string
        - 2.2.2. Try these plans one at a time until one succeeds or they are exhausted:
            - 2.2.2.1. *If* plan seems to be possible to do, then do plan
    - 2.3. If are remembering too many plans, maybe forget one with a bias towards the least valuable
3. Update display, clear dead objects from can-buy lists, do stats and timing

6.2 Design Concepts

6.2.1 Basic principles

In this model, we aim to represent the process of making as directly as possible, given a universe of objects and tasks that allow for this to be meaningfully complex, so that communicating plans is worthwhile, and that there is motivation for trade and/or sharing objects.

Objects are represented individually and explicitly. Some objects can be extracted from the environment by some agents at a cost (depending on their composition). Some objects can be directly used by some agents so they gain value (depending on their composition). Objects can be soft-joined using an "&" (e.g., A and B to A&B) or split at a "&" (e.g., B&AA to B and AA). Some objects can be used to transform other objects, those with a ">" in them (e.g., AB>BA used once on the object ABB would result in BAB. Objects can be passed from one agent to another agent but can only be owned by a single agent at a time. Once used up they disappear from the simulation.

Plans are mental representations of the steps needed to construct/deconstruct strings. They reside in the agent's memory. They can be communicated with other agents, potentially either freely (following some license conditions) or on a commercial basis.

6.2.2 Emergence

Patterns of use and of buying and selling emerge as the simulation progresses.

6.2.3 Adaptation

Agents gradually adapt to what kinds of things are available from their environment, what they can buy and sell and with whom, and what they can directly utilise.

6.2.4 Objectives

At the moment, agents effectively learn to create the greatest value for the least cost, in terms of their own needs or sale values because plans with a higher value are preferentially tested for viability and used. The parameter, prop-targets-each, controls the heterogeneity of agent values, because if an agent cannot directly redeem a string its only value to them will be if they can sell it to another or, possibly, use the string in further construction/deconstruction.

6.2.5 Learning

Agents slowly build up more complex plans and learn which are the most valuable to perform.

6.2.6 Prediction

Agents assess possible plans and predict whether they think the plan is possible to complete as well as the resultant value/cost of doing so.

6.2.7 Sensing

Agents can sense what objects they have, as well as what objects they might be able to buy from others.

6.2.8 Interaction

At the moment, interaction is through the buying and selling of objects. In the future interaction will include the communication of plans.

6.2.9 Stochasticity

There are three main sources of stochasticity in the model:

- the initialisation in terms of what kinds of object are available from the environment or usable by agents;
- each tick each agent picks plans to do probabilistically, with a bias towards the more successful plans. If the plan is one of the default "random" plans this will include choosing random objects to do the actions with;
- if an agent has too many plans in its memory it will probabilistically forget a plan with a bias towards those that are less successful.

6.2.10 Collectives

There are currently no collectives in the model, though there is the potential for collectives to form to collectively "manufacture" items or share tools and plans. Also various market structures and alliances would be simply implementable.

6.2.11 Observation

The statistics that the model currently generates is described in Section 6.4.4.

6.3 Details

6.3.1 Initialization

The number of agents is fixed: they are initialised as "patches" on a 2D grid. Each agent is initialised with the same default plans, which are given values. At the moment these plans and value pairs are: [-2 "get-random"] [-0.75 "apply-random"] [-0.5 "realise-random"] [-0.5 "sell-random"] [-2 "buy-random"] [-1.5 "split-random"] [-1 "join-random"], where [-2 "get-random"] means extract a possible string from the environment using the notional value for the plan of -2 when comparing it with other plans.

The main variation in terms of initialisation comes in what resources and redeemable target strings are available. The total menu of resources and targets is determined as follows.

Environmental resources – This is a list of strings that can be got from the environment and the cost of doing so. This is determined as follows.

1. The basic “elements” (characters not “&” or “>”) are given, the number set by parameter.
2. Random strings using these elements are constructed with a length determined by a Poisson distribution whose mean is given by parameter.
3. A given proportion of these strings have a soft-join (a “&”) inserted with a given probability.
4. An additional number of random tools are generated with the same length distribution.
5. All of these are then attributed a random cost picked from a Poisson distribution with a given mean (if the item is available to an agent in terms of extraction from the environment, then it is with this cost it is extractable).
6. Each agent is then allocated access to a random selection of these, the number determined by a given proportion of the totality.

Target affordances – To ground the value of strings for agents some strings are allocated a redemption value – that is, an agent can get this value by “consuming” this string. Again, like resources, agents may have a different selection of such strings, representing different needs and goals, but always with the same value. The process for initialising these targets and their values are as follows.

1. The basic “elements” (characters not “&” or “>”) are given, the number set by parameter.
2. Random strings using these elements are constructed with a length determined by a Poisson distribution whose mean is given by parameter.
3. All of these are then attributed a random value picked from a Poisson distribution with a given mean (if an agent is able to directly redeem this string, then this is the redemption value).
4. Each agent is then allocated access to a random selection of these, the number determined by a given proportion of the totality.

Thus agents have a hard problem, how to make strings that they can redeem/sell given the strings that they have as a resource/buy.

For example the list of strings that might be extractable from the environment might be: A; A>; AA; AB; B>; BA; BB; A&A; A&B; AAA; AB>BA … and the list that is redeemable in terms of value be: AB; A&B; AAA; AAB; ABA; B&A; BBA; BBB; A&AA …. Inspecting these one can see that A&B might simply be both extractable and consumable; A&AA could be made by joining A and AA, both of which might be available in the environment; to make B&A one would have to obtain A&B, split it apart and rejoin it as B&A; and to make AB one might have to apply the tool AB>BA on the item AB. Making items of high value might require a very complex series of steps, and some maybe not possible to make. This is more difficult because each agent will only be able extract a different subset of resources and redeem a different set, which provides a motivation for commerce and sharing of items.

The parameters that control this environmental framework of resource cost/distribution and target value/distribution determine how hard the making problem is for agents and whether it will be useful for them to trade. A very hard framework would make the discovery of plans that allow the construction of valuable items important, a great heterogeneity in terms of resources encourage trade, but the heterogeneity of targets might encourage the emergence of streamlined production (i.e., manufacturing).

6.3.2 Input Data

At the moment, there is no data input.

6.3.3 Submodels

The key global data structures are as follows.

Name	Purpose	Fields	Notes
resources	A list of strings that could be available to agents		Each agent might have only access to a subset of this
targets	A list of strings that can be directly realised for value		Each agent might be only able to realise a subset of this
resource-costs	This is a table showing the costs of extracting kinds of resources	str → cost	
target-values	This is a global table showing the value of directly realising strings	str → value	

The key agent data structures within agents, are currently as follows.

Name	Purpose	Fields	Notes
my-resources	The subset of resources that the agent can access		
my-targets	The subset of targets that the agent can realise		
my-plans	An agents plan library (a factbase)	str, id, value, plan, plan-hash	and plan is one of the following (recursive) lists * get itm * buy itm agent * realise itm-tree * sell itm-tree agent * apply tl-tree itm-tree * split itm-tree * join itm1-tree itm2-tree * plus the random plans: "" val plan – -1 [buy-random] – -1 [get-random] – 0 [split-random] – 0 [join-random] – 0 [apply-random] – 1 [realise-random] – 1 [sell-random]
plan-table	A table to speed up plan location	thing → plan id	
for-sale	A factbase of items offered and available for sale, agents must check this before	str, itm, price	Is kept up-to-date by selling agent

	buying		
can-buy	A factbase of information about items agent could buy	str, itm, price, agent	This might be fallible, as the item might be sold, but is used by a buying agent to see what might be available

In a sense, the algorithm of agent learning and decision making is a submodel, but that is described above. Obviously, at this stage this is pretty basic.

In terms of the market in the model, this is pretty basic. Each agent has a “for sale” list of things it would like to sell, with their price. They also keep a (fallible) list of things they might buy derived from others’ for sale lists.

6.3.4 Parameters

Apart from some debugging options, the model has the following parameters:

- num-agents – sets the number of agents in the simulations;
- num-elements – the number of different characters (“A”, “B”, …) that can be used to construct strings;
- num-resources – the number of strings that can be extracted from the environment;
- cost-resources – the average cost of obtaining resources from the environment (the distribution is a Poisson with this as the mean);
- len-resources – the average length of resource strings (the distribution is a Poisson with this as the mean);
- prop-resources-each – the proportion of all resources that each agent can access (each agent will get a random selection);
- prop-breaks – the proportion of resources strings with “soft joins” inserted into them (“&”);
- prop-nat-tools – the proportion of resource strings that are tools (i.e., with “>” in them);
- num-targets – the number of target (directly redeemable) strings there are;
- value-targets – the average value of the targets (the distribution is a Poisson with this as the mean);
- len-targets – the average length of the targets (the distribution is a Poisson with this as the mean);
- prop-targets-each – the proportion of the total list of targets that is randomly made accessible to each agent;
- num-plans-remembered – the maximum number of plans that an agent remembers, if this is exceeded then probably some will be discarded;
- max-tries – the number of different goal strings (derived from its plans) an agent will consider each tick;
- num-alternatives – how many different plans for each goal stings are considered and compared;
- tool-use-cost – the cost of using a tool;

- choice-bias – the bias towards trying plans that are remembered with a higher value (0 means choice is random, and higher numbers mean that there is less exploration of lower value or random plans);
- dup-discount – the drop in value for a plan that produces an item the agent already has (0 means it does not care about producing duplicates, the higher this number the less likely a duplicate might be made);
- action-cost – the cost of doing any action, thus doing complicated plans costs more than a simple one with the same result (0 means no bias towards simpler plans);
- max-time – the max number of ticks the simulation will run for (0 means no maximum).

There are also a number of debugging options which do not affect the results of the model (see below in Section 6.4.2 for some of these).

6.4 Simulation Outcomes

6.4.1 Model View

The model view is shown in Figure 2 above. Each patch is an agent (patches that are not agents are coloured black). Things are represented on the patches, with their label being the string they represent. The colour of things indicates the last kind of action that was used in making it, according to the following associations:

- Apply – red;
- Split-left and split-right – green;
- Join – blue;
- Get – brown;
- Buy – orange;
- Sell – magenta (in practice this will not appear, since everything sold is also bought by the recipient);
- Realise – violet (in practice this will not appear, since once it is realised it disappears).

Items that are tools are put to the upper right hand side of patches and displayed as crosses, non-tools to the left hand side as circles. The yellow number in the bottom right hand corner of patches is the (cash) value they have. When an item is sold or transferred an arrow is shown from patch to patch.

6.4.2 Model Output

The main detail of what is happening is shown in the text displayed with the output window to the right. What is shown here depends on the debugging options above this. If debug? is true then the calling of every high-level procedure is shown along with values it is called with. If trace? is true then only the actions of agents are logged. Setting aft-go? to true means both of these only have effect after setup is finished. If any string is entered into the filter-string box then only those lines which include this string are shown, allowing logs that only record what happens to one agent etc. If the pause? option is enabled then the code will pause every time it reaches a “_p” statement in the code, to facilitate step-by-step debugging.

6.4.3 Monitors

There are currently 4 monitors:

- resources – which shows the start of the global list of possible resource strings;
- targets – which shows the start of the global list of possible targets for redemption;
- s/tick – which shows the average seconds each tick takes;
- Num.Th. – which shows the total number of things in existence.

6.4.4 Output Statistics

If the stats? option is set, various statistics are generated, for use with the behaviour space. This generates a number of lists of numbers, one number for each agent in the list at any tick. These are lists of:

- num-things-list – the number of things that each agent has;
- num-tools-list – the number of tools that each agent has;
- num-distinct-things-list – the number of different things that each agent has;
- av-length-list – the average length of thing strings that each agent has;
- num-get-list – the number of get actions each agent has done;
- num-buy-list – the number of buy actions each agent has done;
- num-sell-list – the number of sell actions each agent has done;
- num-join-list – the number of join actions each agent has done;
- num-split-left-list – the number of split-left actions each agent has done;
- num-split-right-list – the number of split-right actions each agent has done;
- num-apply-list – the number of apply actions each agent has done;
- num-realise-list– the number of realise actions each agent has done;
- num-plans-list – the number of plans that each agent has;
- num-for-sale-list – the humber of sales each agent has achieved;
- max-plan-value-list – the value of the most valuable plan that each agent has;
- income-list – the income in the last tick that each agent has made/lost;
- money-list – the money that each agent has.

These can be used in the "Measure runs using these reporters:" box of the BehaviourSpace dialogue, in conjunction with "av", "sd", etc, e.g., av num-things-list, max num-things-list or sd num-plans-list.

6.5 References in Annex

Edmonds, B. (2016b). A Model of Making, Slides from the DiDIY Project meeting, Thessaloniki, Greece. http://slideshare.net/BruceEdmonds/a-model-of-making.

Edmonds, Bruce (2016a). A Model of Making. CoMSES Computational Model Library. Retrieved from: http://www.openabm.org/model/4871.

Netlogo Extensions. http://github.com/NetLogo/NetLogo/wiki/Extensions, accessed 5th Feb 2016.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.