More Time for the Doing, Having *Made* the Thinking
3D Printing for Knowledge Circulation in Healthcare

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Abstract: This paper investigates the phenomenon of the Digital Do-It-Yourself (Di-DIY) in the medical domain. In particular, the main contribution of the paper is a conceptual framework based on the notion of DiDIY in healthcare. To help focus on the main actors and assets composing the 3D printing innovation roles in healthcare we model: the DiDIY-er as the main initiator of the practice innovation; the available technology allowing the envisioning of new practices; the specific activities gaining benefits from the innovative techniques introduced; and the knowledge community continuously supporting and evolving knowledge practices. A general introduction on the notion of Knowledge Artifacts (KAs) and on the use of 3D printing (3DP) in medicine will be followed by our research questions and by a more detailed analysis of diagnostic, training and surgical planning activities for clinicians and patients. Observations carried out in a hospital in Italy are reported to exemplify activities based on 3DP bone models in the radiological and orthopaedic fields. These observations can be considered a second contribution of the paper, although secondary with respect to the conceptual framework. They also help proof how knowledge sharing and circulation in the community of healthcare professionals may be improved by the introduction of tangible and intangible KAs around the practice of DiDIY. Our framework is then presented in the end.

1 INTRODUCTION

A knowledge artifact has been defined (Cabitza et al. 2014c) as *any artifact that is purposely designed to support knowledge-related activities* in any practice. Although this is an (intentionally) broad definition, it allows to exclude most of the tools that are used in the human activities where users do not rely on these tools to take decisions, access a body of notions that are useful to interpret or understand a situation, or to solve a problem and complete a task relying on past experiences and solutions.

After a comprehensive survey of the varied literature available on this matter, Cabitza and Locoro (2014a) identified two main perspectives along which to conceive this class of artifacts: *objectivity* and *situativity*. These are seen as two extremes of a broad spectrum of application solutions, which often offer functionalities that cannot be traced back to only one extreme but rather lie in between. What do these two terms refer to? At the former extreme, there lies the idea that knowledge can be expressed in explicit and linguistic forms, in terms of guidelines, procedures, rules and notions. As such, knowledge is somehow quantifiable (e.g., in terms of how many statements, rules, notions constitute it); it exists independently of any possible consumers, like a book on a library shelf; and it can be transferred from one place to another, e.g., by email or a courier. Therefore knowledge is seen as if it were an *object* for any practical purpose (hence the name of the approach). At the situativitist extreme, instead, knowledge is assimilated to a *knowledgeable behavior* that competent people exhibit *during a specific situation and within a social practice*. This latter is seen as a set of activities where more or less explicit rules and conventions that are shared within a social group stipulate and normate the right way to have things done, and where an often totally ineffable know-how allows the practitioners to accomplish their tasks. In the situativist case, KAs are those artifacts that enable the sharing of ideas, the learning process and the mediation of collective activities of problem framing, agreement reaching and decision making, without knowledge being

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objectified in any form (neither as written facts nor written rules) as above.

This objective-situative spectrum regards the *degree of specification* (high in objective KAs and low in situative KAs – Cabitza et al. 2013) and the very way in which knowledge is conceived (cf. objectivism vs constructivism – Vrasidas, 2000). In this contribution, to this dimension we add two further dimensions regarding *interactivity*, and *tangibility*. KAs can be either passive or interactive. And they can be either tangible or intangible.

The latter dipole allows to distinguish, quite sharply, between software applications and physical, tangible objects. The former KAs are certainly "physical" (and often even material) in that their users can perceive them, but their way to show themselves is through patterns of energy and matter that could hardly be touched (in this light a mouse is just a tangible controller to move a pointer on the screen, but the real application regards bit of energy in memory modules or pixel grids). Tangible objects, which we all are very familiar with, are usually passive, but this is not necessarily always the case: a washing machine, for instance, can be touched (indeed, it is even quite heavy) but through some controllers it can also respond to the users' commands and settings and through sensors can "take decisions" on how to proceed in carrying out its washing programs. On the other hand, not all of the intangible (software) objects are interactive in the same way, nor necessarily so their level of interaction matters. For instance, the Wikipedia, although it is a very comprehensive and convenient source of knowledge (in an objectivist viewpoint), responds to the user's textual query and allows just to open new pages from the links of another one, that is a sort of basic interaction; but it is not proactive in its provision of knowledge nuggets, facts, taxonomies and procedures, as an expert system would be; rather it is reactive. To the other extreme, there are decision support systems, that is software systems that, once been fed in with the available information about a case, suggest ways to classify, treat or manage it (e.g., in the healthcare domain, in the legal one and in Customer Relationship Management). These are very interactive intangible KAs, which can even surprise its users (and indeed rightly so they consult it to get indications they still ignore).

In our studies, we identified two extreme examples of KA: shapes produced with 3D Printing (3DP) technology, in particular bones and anatomical parts printed by radiologists and orthopaedic surgeons. And social media that support the practices of the professional roles mentioned above, by providing videos, blog articles, guides and a place for DIYers, makers and 3DP enthusiasts in the orthopaedic surgery domain to ask questions and exchange advice. This latter case also regards the increasing use of intangible and interactive KAs that can support (in a more less objectivist/situativist manner) the pioneers and early-adopters of 3DP technologies for their delicate and often very difficult work (consisting in very complex surgery aimed at correcting important deformities and alleviating multiple pathological conditions).

Although both cases are important and worthy of further research, in this paper we will focus on the former case, 3DP, in order to both keep the scope of the paper circumscribed, and also to acknowledge the increasing relevance of the literature contributions on embodiment (Dourish, 2001; Lakoff & Johnson, 1999; Varela et al., 1991), which argues for a close link between physical activity and cognition and on the role of physical manipulative materials in supporting learning (Rybarczyk & Fonseca, 2012; Hornecker & Buur, 2006; Pernin et al., 2012). In the same vein, we observed how relying on situativist, tangible and passive KAs, rather than only 2D representations, improved planning, communication and decision making in the orthopedic settings we studied. In what follows, we will interpret these observations referring to the concept of *Digital Do-It-Yourself* (DiDIY), that is a complex phenomenon that we are characterizing within the DiDIY EU funded project (DiDIY, 2016) in which either an *amateur* or a *professional* (which we call DiDIYer) builds up material artifacts by herself with 3D printing technologies *for her job and daily work, without the aid of specialists*.

1.1 Research Questions

Our research topic focuses on the impact of Digital Do-It-Yourself (DiDIY) and 3D printing (3DP) on the healthcare practices, training and communication processes. All of these ambits have in common the exploitation of knowledge and knowledge artifacts in different forms (Cabitza et al. 2014c). Healthcare practitioners rely most of the time on a kind of tacit knowledge based on their training, "situation specific wisdom", and narrative exchange of real cases with their peers (Greenhalgh and Wieringa, 2011). Traditional training techniques in health education are mostly based on human cadavers dissection and inspection, either for school teaching or pre-operative simulations (McMenamin et al., 2014; Regier et al. 2010). Finally, pre-surgical, intra-operative and patient-specific communication are well known to be delicate moments where improving the awareness for patient consenting (de Mel, 2016; Starosolski et al., 2014; Regier et al., 2010), the shared understanding in surgical rehearsal (Mitsouras et al. 2015) and the rapid decision-making during the ongoing operation may be of vital importance.

Consequently, our research questions regard whether and how DiDIY processes and artifacts may influence, enhance and guide the mechanisms of knowledge circulation (Cabitza et al., 2014b) in medical settings, and in particular in radiological practice either by single doctors or in cooperation with other clinicians. In summary, they are the following:

- Do 3DP artifacts modify diagnostic and therapeutic decision making?
- Do 3DP artifacts modify training and teaching in radiology?
- What are the dynamics of knowledge circulation between members of hybrid communities and the hospitals where they work?

Some preliminary answers can be found in this study, where we elaborate a DiDIY framework tailored on the specific healthcare domain that should help focus on the main actors, technologies, activities and communities involved.

We report in this study some early reflections, on the basis of the specialistic literature and of the existing online communities, mentioned in Section 2, and in observational studies carried out in an Italian hospital, from which some vignettes have being extracted and are reported in Section 3 and discussed in Section 4 where we introduce our framework; Section 5 draws some conclusions on our study.

2 BACKGROUND

2.1 The Technology at Hand

In the healthcare literature, 3D printing is finding its place in different facets of the professionals practice. We will shed light in particular on the practice of surgery, orthopaedics and radiologists, starting from the technical process of medical 3DP.

For reproducing patient-specific anatomy, 3DP objects are generated from medical imaging acquired through either Computer Tomography (CT) in its several variants (e.g., Multidetector Computer Tomography (MDCT), Single Photo Emission Computer Tomography (SPECT), and so on) and Magnetic Resonance Imaging (MRI). A second step of this elaborate acquisition is the saving of imaging data into Digital Imaging and Communication in Medicine (DICOM) format. A further step consists in the 3D rendering of the image, by segmentation techniques, which can be manual, automatic or semi-automatic (Auricchio and Marconi, 2016), depending on the complexity of the data managed. Segmentation allows to place regions of interests on the images for further volumetric refinement (Mitsouras et al., 2015). During segmentation, a 3D model of the acquired image is rendered as a geometrical transformation into a set of triangles (called mesh), which allows the data to be readable by a 3D printer. One of the most common 3D files format for 3D object printing is the Standard Tessellation Language (STL), which refers to the property of the image to be represented as a set of triangles, at different degree of precision (or smoothing). Commonly, a 3D model is then virtually cut into equally-thin horizontal slices, and each slice can be printed in various materials (e.g., “powder, resins, filaments and hydrogels” – see de Mel, 2016 and Mitsouras et al., 2015) and laid down as a layer of the 3D object. Each slice is then fused together with the just printed layers, according to disparate techniques using chemical and physics processes (e.g., photopolymerization, material jetting, material extrusion, powder bed fusion, sheet lamination, direct energy deposition, and so on – Auricchio and Marconi, 2016; Rengier et al., 2010; Malik et al., 2015). Figure 1 depicts some main passages from the acquiring of an image to the printed object.

2.2 A Quick Glimpse at the Literature

A 3D printed object is very different from a 3D virtual object. Recent comparative studies of 3D virtual and material objects in manipulation tasks have shown that “performance during the activities was significantly higher when using tangible representations” (Cuendet et al., 2012). In healthcare domain, this has proven to give a pre-operative visuo-haptic capability to physicians of unprecedented flexibility and precision (de Mel, 2016). 3DP objects can be exploited to gain a huge amount of patient-specific detailed and clear information before a complex surgery takes place, for example in case of deformities correction. Obviously, not all the activities need the use of 3DP, and this is especially evident in diagnostics and classification tasks (Mitsouras et al., 2015). A literature survey (Malik et al., 2015) on around 500 papers retrieved from Medline, Embase and PsychInfo databases, helps detect the three main areas where 3DP is currently exploited in surgery. They are: anatomic models,

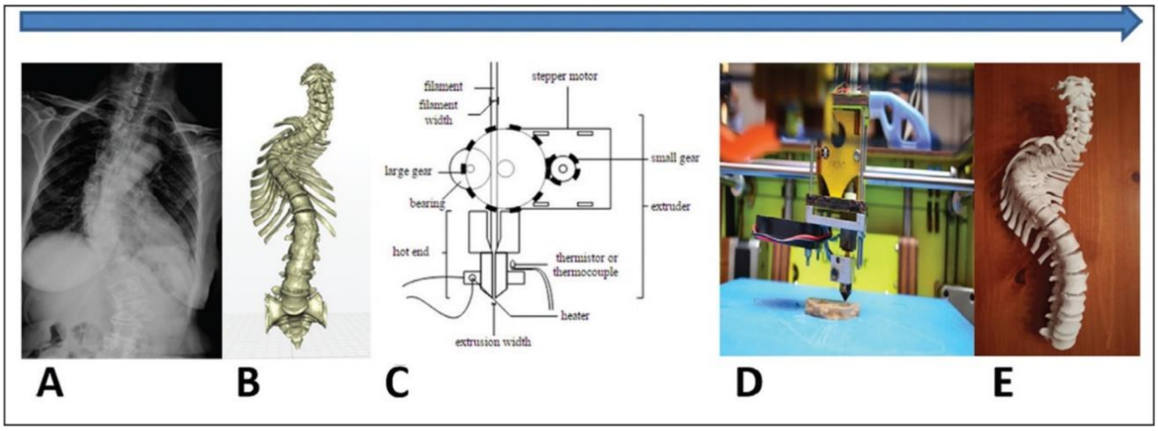

Figure 1: The process from the virtual image to the printed object, taken from Eltorai et al. (2015).

medical devices like surgical instruments and implants, and prostheses. Anatomic models are used by doctors to familiarize with the patient anatomy in surgery planning, and help them reflect on the challenging and risky passages of an operation well in advance. This patient-specific appreciation overcomes traditional simulations (see, for example Malik et al. 2015; Rengier et al., 2015). In some cases, for example cardiothoracic surgery, bespoke heart models are exploited either for planning and for intra-operation activities. Young surgeons can be trained (Malik et al., 2015) through the manipulation of these objects besides traditional virtual patients environments (Cabitza et al., 2016), which help "simulate in vivo conditions and real tissues without any risk of patient complications" (Rengier et al., 2015). Also patients and their family may be better informed on the pathology at hand and the necessary therapy, and this helps the psychological conditions under which a surgery can be understood, accepted and perceived as satisfactory (Malik et al., 2015).

In orthopaedic surgery, where "radiographs are used routinely […] yet they provide inadequate information on the precise 3D extent of bone defects" (Auricchio and Marconi, 2016), 3D models are exploited to assess tools trajectories, to measure and prepare materials for fixing bone fractures and placing plates and screws in advance (e.g., assessing surgical manoeuvres for the placement of pedicle screws in spinal surgery). Patient-specific guides and templates are also printed in 3D and used during the operation as supportive devices that are removed at the end. In the maxillofacial reconstruction or in the implants placement, for example, these kind of devices have reduced the time of operation and improved the efficacy of the outcomes (Malik et al. 2015).

In low error-tolerance scenarios, such as for example in neurosurgery, the 3D reproduction of the skull or of the tumors may help understand the exact resection boundaries and provide a level of accuracy that reduce risks, operation time and the number of errors and adverse events (Mitsouras et al., 2015).

A pivotal factor in favour of the manipulation of medical imaging for 3DP technology adoption is that radiologists and radiographers, as more and more "image guided surgeries call for radiology to become strongly integrated in a therapeutic team together with different surgical specialists" (Rengier et al., 2010) are acquiring prominent roles. However, open issues rise in the passage from data images into 3D prototypes as this encompasses "a multidisciplinary array of fields involving knowledge ranging from data acquisition, image post-processing and manufacturing of the prototype by various techniques" (*ibidem*). The authors contend that although radiologists may facilitate the introduction of additive manufacturing in healthcare, this integration would result difficult, if feasible at all, without a close cooperation with other roles such as computer scientists, material experts, clinicians and other healthcare professionals.

At the frontier of 3D printing technologies we also mention bioprinting, i.e., the reproduction of cellular tissues and the related organs for implantation in human bodies. Since research studies are still preliminary, we do not treat them here and refer the interested reader to the overview by Mok et al. (2016).

2.3 Online Communities in the Medical Field

Communities in the field are those of physicians who meet periodically with 3DP professionals in their universities, institutions and research centers, where a broad spectrum of experimental activities takes place. This aspect is witnessed for example by our observational studies reported in Section 3.

Virtual communities of makers exist and gather around online platforms such as 3D Slicer (Fedorov et al., 2015), an MIT initiative, which provides a mature, open source, and fully-fledged software platform specialized in "image guided therapy". Intelligent online platforms such as POIGO (Popescu et al., 2015) aim to integrate medical expertise with the manufacturing of tools for the so called personalized surgical templates, an increasing popular range of tools for helping surgeons customize their operations around their patients, and reduce costs, risks and adverse events.

Other kind of tools are online blogs and reference websites that help gain knowledge on specific health topics and techniques, and are tailored for specialists of different kind; for example: the Italian blog "Fermononrespiri" (http://fermononrespiri.com/) where discussions on MRI, CT, and diagnostic by images are the main topics discussed by the participants to the online forum that the website provides; "Embodi3D" (http://www.embodi3d.com), where a virtual community gathers around virtual spaces such as blogs, forums, textual tutorial and "how-tos" for 3DP, a marketplace where to buy and sell biomedical models, and a training section with training models, realized with the aid of health professionals (e.g., 3D vascular models such as venous models and arterial models).

3 OBSERVATIONAL STUDIES

In our study, we had the opportunity to carry out two observational studies in the Marino hospital in Cagliari, Italy. This hospital is near to be dismissed, since the recent regional policy making decision of cutting administrative costs. However, currently the hospital hosts healthcare figures of both professional and academic kind, in the two local specializations of traumatology and emergency surgery. The hospital is one of the only two hospitals in the Sardinia Island equipped with hyperbaric chambers. Its main areas of orthopaedic expertise are hip and knee surgery, upon which we will focus our investigation. In particular, we will examine a case where the introduction of additive manufacturing (3DP) has been used to support the planning and pre-operative training of a knee prosthetic surgery.

This is not the case of an ex-novo, patient-specific 3D printing of a knee prosthesis (re)production, but of a traditional bone-prosthesis replacement, with the support of an anatomic model of the patient bones, exploited to support and enhance the outcome of a traditional surgical practice.

We depict in the following two vignettes on how 3DP is used to inform and educate the patient to know more of his pathology and of the subsequent therapy, as well as for surgical rehearsal.

3.1 The Patient Informed Consent

It is Monday morning. Today Prof. Bones will explain the pros and cons of the procedure of knee replacement surgery that Marco Poli (male, 58 years old) will decide to undertake or not. In case he decides to do it, he will sign the informed consent form.

Prof. Bones, the orthopaedic surgeon, met Mr. Poli previously and, during that occasion, he prescribed to him routinely examination tests such as blood, urine, drugs intolerance, and a radiography. By reporting the radiologist report of this last exam Prof. Bones realized the morphological deformities and damages affecting the patient's knee joint and the need for Mr. Poli to undergo a surgery.

For this reason, once the surgeon analyzed the report, he prescribed to Mr. Poli a second and more complete diagnostic examination: a CT, with the aim to obtain from it a 3D dataset in DICOM format and, hence, to use addictive manufacturing to create a patient-specific anatomical model before the meeting with him during the day hospital session. In so doing, Prof. Bones could further investigate the patient-specific problem and let Mr. Poli see and touch first hand the tangible representation of his condition, through the replica of his irreversibly injured articulation.

Monday it's the day where other tests are done, more extensive and specific, to gather information about the patient's anamnesis. In particular, physical examinations are aiming at assessing movement, stability, strength, and alignment of the patient's joint, and a more specific test (an MRI) was aimed to better analyze the anatomy of his soft tissue (muscles, tendons, and cartilage).

The study of Mr. Poli's anamnesis already showed a compound fracture dating back to when he was 32, which involved the femur to come closer to the same left knee region now under examination. In addition, during these last exams, Prof. Bones evaluates the condition of the damage caused by post-traumatic arthritis, which severely limits the patient in articular functionality by afflicting him with persistent pain, and pronounce himself in favour of the joint replacement as a treatment of election.

Figure 2: A 3DP spine with implanted nails for pre-surgical rehearsal.

Now Prof. Bones is ready to talk to Mr. Poli, who may appreciate his own case also with the aid of anatomic models reproducing his articulations, and that the surgeon made ready before their meeting. Thanks to them, the surgeon can show with precision to the patient which parts of his knee are irreducibly deteriorated, which operation Mr. Poli should undergo to his bottom femur and top tibia to let the articulation work out again, and to hypothesize with him the exploitation of the proper traditional prosthesis having the best dimensions similar to his original bones.

In so doing, Mr. Poli understands vividly his case, and is able to integrate these information with those reported in the informed consent form. Mr. Poli, under a mood of psychological relief for the awareness gained during the meeting with the surgeon, agrees to the operation.

3.2 The Surgical Planning

The Friday before, the orthopaedic surgeon met the radiologist to discuss in more details the case at hand and asked him whether he recommended to run a further test in order to use additive manufacturing with the case at hand. The radiologist proposed to do an MRI scan, and to call Dr. Bolt, who is a professional consultant in the field of additive manufacturing and 3D technologies applied to prosthetic surgery, with the aim to print a 3D model of the patient's joint bones. In particular, the radiologist asked Dr. Bolt to do an evaluation of the most appropriate acquisition parameters, in order to optimize the effectiveness of the dataset for later use with additive manufacturing technologies.

Both MRI and CT results are exploited in order to obtain the most accurate reproduction of both the hard and soft tissues of the patient-specific anatomical model.

The surgeon then calls the professional consultant, with whom he agrees upon which are most appropriate materials and processes to be used. An anatomical replica of the patient's hard tissues should be produced by using Fused Deposition Modeling (FDM) technology and Polyethylene terephthalate glycol-modified (PETG) material, as this can be submitted to antibacterial sanitizing processes, if necessary. An anatomical replica of soft tissues should be produced by stereolitography (SLA) and photosensible resin, which is a soft and flexible material that could be also compatible with some sanitizing procedures.

Thanks to the 3DP custom-made models the surgeon and his team may start the surgical planning. The surgeon studies the osteotomy planes, performs measures of trajectories and lengths of the necessary perforations by simulating them directly in the anatomical models.

In so doing, the surgeon may transfer all the necessary data to the consultant, so that he can in his turn create the anatomic replicas, the surgical guides and all the supporting material for the operation. For example, he may prepare the osteotomy planes in the custom-made models with the cuts and the holes already performed on them, through FDM and SLA technologies, and under the direct supervision of the surgeon, who can simulate the operation moments in minute detail.

The software used in this phase allows the application of osteotomy planes and holes, the creation of scaffolds for dimes and the 3D models availability of virtual existing surgery environments.

Furthermore, in case that a prostheses has undergone a 3D scanning process or simply its 3D models are available from the manufacturer, it is possible to pre-operatively overlap 3D prosthesis models with custom-made anatomical models, so that the prostheses fitting the patient's bones size can be easily selected.

After this surgical rehearsal, some comparisons and verifications of the obtained results are still possible. In this sense, the surgeon verifies all the pre-operative process details by applying a real prosthesis of the same size of the one used in the surgical planning phase.

3.3 Some Cost-effort Data and Lessons Learnt

3DP is not cost nor effort free. In the specific cases, different phases before the printing were carried out, namely: image of bones acquisition; DICOM data storage and transfer (after the clinicians' decision on what to print); rendering, segmentation and triangulation for the generation of the 3D model; further editing and preparation (with the aid of the clinicians); slicing and G-code generation (for programming the printer). These pre-printing activities takes on average from 4 to 20 working hours. The printing of the patient-specific bones took around 50 hours. The costs depend on the printing technologies (e.g., either Stratasys or MakerBot printers, whose costs vary from 60.000 to 4.000 euros, respectively), on the materials used, and on the level of standardisation of these materials with respect to standards such as ISO and so on. For the case at hand, these may vary from an average of 50 to 250 euros per kilo. In the specific case, the 3DP bones were accurate enough to guarantee similar material characteristics (e.g., density and resistance).

The most critical and error-prone passage was the activity of conversion from ERM raw data into DICOM data. In general, this is the most delicate passage and the one where both radiologists, engineers and other experts are requested to cooperate and coordinate their work and competences. As a general lesson from our experience, we may report that costs and efforts were considered affordable and the exploitation of the cheapest printer (the MakerBot one) did not compromise the quality of the work and the satisfaction of both the patient and the clinicians in manipulating the 3DP bones.

4 A DIDIY FRAMEWORK

The DiDIY project (http://www.didiy.eu/) defines DiDIY as human-centered phenomenon characterized by the diffusion of:

- a mindset among individuals: the "DiDIYers";
- a set of activities enacted by DiDIYers: the "DiDIYing".

The latter activities are intended as pragmatically translating in a context the abstraction of mindset of an individual and, as a consequence, natively overcoming the level of analysis of the single individual. In DiDIY digital technology is an "enabler", but the very existence of DiDIY does not depends on the presence of digital technology, as its core properties are human-centric, thus related to individuals' mindsets and activities.

In short, according to this approach an individual can be defined as a DiDIYer when, due to her mindset: (i) she uses to "do things" on her own that had been previously carried out by experts or specialized companies (this aspect deals with the traditional notion of Do-It-Yourself, or "DIY"), and (ii) these "things" could not be "done" without digital technology ("Di"DIY).

Under this premise, an operational definition which enables the identification of DIDIY activities is the following:

a) a DiDIYer, i.e., certain organizational roles
b) carries out on their own certain activities,
c) by exploiting certain digital technologies;
d) possibly exploiting the knowledge sharing within a certain *knowledge* community (Cabitza et al. 2014c)

According to this definition and to our preliminary research, we instantiate its four dimensions in the medical domain, as follows:

DiDIYers: are the healthcare professional whose skills are those of a digital craftsman. This role can be played for example by doctors, surgeons, nurses, technical clinicians (e.g., radiographers). In particular our research focused on two main roles and activities:

- the *Radiologist*, in her diagnostic and prognostic activities, who runs examinations with proper technologies and acts directly or highlights to her colleagues actions to be taken, based on all the medical information gathered during the analysis of examinations results. State-of-the-art information are bi-dimensional representations (axial, coronal and sagittal planes) of the analyzed anatomical parts or, at last, 3D visualizations available thanks to 3D dashboards provided by the ultimate diagnostic tools. Whenever there are strong interpretation misalignments of diagnostic examinations, for example in case of congenital deformities, the radiologist joins the surgeon (or her collaborators) in order to analyze the examination together, so as to reconcile meaning and proceed the activity with the aid of a complex however complete set of information;

- the *Surgeon*, in her therapeutic activities, who applies her surgical specialty methodologies. She needs to collect the most part of information before taking decisions and actions that are neither diagnostic nor prognostic, hence they are not at all repeatable. For this reason, the surgeon needs the support from her colleagues, and in most complex scenarios, even from other healthcare professionals, such as for example clinical engineers, other specialists, consultants and so on.

Technology: is the elective tool of the DiDIY-er to improve her activities or to face them in innovative ways and under unusual perspectives. The technologies involved in the healthcare domain encompass: 3D datasets from physical objects through scanning and diagnostic image acquisition; 2D visualizations of physical objects, through DICOM files or CAD software; 3D manufacturing of physical objects. In this sense, 3DP amplifies the capabilities to go from bits to atoms back and forth (*blinded reference*).

Activity: is the (knowledge) practice of the DiDIYer; it is the daily routine that a professional carries out alone or as a part of a community. The use of technology should improve and innovate her daily activities, so that a virtuous circle can be triggered, and creativity and new skills can emerge and flow freely, also thanks to her network community. Medical practice is peculiarly “practical”, and tangible and intangible information concur to define the logic of “knowing how to do it” or DIY. In the words of an orthopaedic surgeon (Malik et al., 2015) that we adapted to emphasize the importance of tools that improve the situated awareness and support more critical scenarios during surgical operations:

“Having the chance to perform on a 3D model all the necessary steps preoperatively, valuable time is saved and surgeons have more time to focus on the present moments: *you have more time for the doing, having made the thinking*”

Community: can be offline, online or both, and encompasses individuals who are either contextualized in physical meetings and workshops or in the virtual spaces of an online environment. In communities people can find inspiration for new ways of doing things while exchanging and sharing knowledge. The community is the vehicle to share experiences, results and open new ways and directions to practical problems.

In the medical domain, cross-fertilization has a pivotal role: during conferences or pre-operative meetings, surgeon together with radiologists, biomedical engineers, and other medical team members may share heterogeneous knowledge and competences and find a synergy to solve problems, propose solutions or simply hypothesize new healthcare trajectories and allies.

5 CONCLUSIONS

In this paper we have investigated how healthcare professionals may be helped in sharing knowledge and cooperating thanks to 3DP resources and 3D objects, seen as either intangible and tangible (respectively) Knowledge Artifacts (KAs).

In so doing, we have illustrated as the printing of virtual 3D objects into tangible material artifacts does not regard only the transition “from bits to atoms” (Bull & Garofalo, 2009). Rather it also pertains the transition from digital objects to “matters of fact” (i.e., physical objects) and eventually to “matters of concerns” (Latour 2004), that is *things*, to discuss both *about* and *around*. The physical availability in an increasing number of work settings of this kind of *things*, through a making-oriented and DIY attitude, creates opportunities also for other kinds of *social* making, like sense making and decision making (in our case, among health practitioners) and enrich these activities in ways that are still to be explored.

In particular, we illustrated this phenomenon in two vignettes taken from our observational study:

1) the orthopaedic surgeon talks with the patient, who is going to undergo a surgery for the replacement of his knee joints, by showing him details of his injury and the necessary operation details with the aid of a custom-made 3D anatomical model. This KA helps the patient “see” his situation more clearly and take a more informed decision on the surgical operation;

2) the orthopaedic surgeon talks with his team members to discuss the details of the surgical

operation and to test in advance the prosthesis against the patient-specific 3D reproduction of the knee joint articulation (the KA). In so doing, a relevant amount of time can be saved for settings and measurements, and the KA can help reduce the operation time, improve safety and lead to better outcome.

As purported in the specialist literature and confirmed in our observational studies, 3DP has got a potential to change the work of surgeons, both in regard to surgery planning, and in educational activities with novices, as well as in the communication with the patient. In this sense, medical 3DP objects represent a new toolkit of KAs available to prosthetic practitioners, as these artifacts allow for the patient-specific configuration and setting of the main parameters and measurements that can be tested before the surgery takes place. In this light, further research should be aimed at understanding whether prototype replicas can help practitioners replace the more traditional “diagnostics by imaging” paradigm with a complementary, if not alternative, one: a “diagnostics by volumes”, which would enable the emergence of new knowledge circulation practices and habits.

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