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Communication and Decision Support Tool for an In-Hospital 3D Printing Service

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Abstract. *Background*: Effective communication is a key factor in healthcare, essential for improving process efficiency and quality of care. This is particularly true in new services, e.g., the 3D printing service inside the hospital. *Objectives*: A web platform, called 3DSCT, has been developed to act as an interface between the three categories of operators involved in 3D printing: physicians, radiologists and engineers. *Methods*: The 3DSCT platform has been designed using Microsoft Visual Studio Code, enclosing .js scripts and HTML pages with the relative CSS formats. *Results*: When applied to a real 3D printing service, the 3DSCT platform provided an effective solution that streamlined the process of designing and manufacturing 3D-printed artifacts, from physician's request through development to printing. *Conclusion*: By incorporating the platform into the hospital management system, it will be possible to reduce the overall lead time and decrease the waste of time for the operators involved in 3D printing inside the hospital.

Keywords. 3D-Printing, Communication, Clinical Decision Support System.

1. Introduction

One of the challenges that arose in recent years is to improve the quality of healthcare services while optimizing the use of resources in terms of both money and time. For example, it has been measured that, in an average 500-bed hospital in the US, communication deficiencies cause an average loss of 4M$ a year [1]. Information technologies provide great help in promoting communication and could therefore be integrated into clinical routines to reduce such inefficiencies [2]. Moreover, closeness between actors is also known to facilitate the exchange of information, which pushes towards services internalized inside the hospital, rather than outsourced.

The exploitation of web platforms for the sake of communication in healthcare has been extensively investigated with regard to the exchange of information between physicians and patients. It has been proven that the physician-patient relationship cannot rely anymore on a pure face-to-face approach. On the contrary, it is enriched by the digitalization of the information flow, which allows to shift from a communication *in fits and starts* to an *ongoing* one. Well-known applications are: electronic and personal health records, biometric and telemedicine devices that help diagnose and disease

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treatment remotely, and patient-focused internet applications (also called apps) that acquire health-related information [3]. Other works explored the benefits of technology-supported communication for nurse leaders [1]. However, platforms that allow communication between different operators with different backgrounds are only marginally considered, yet.

A service that could benefit from this innovation is certainly the production of 3D-printed artifacts for medical use. These artifacts support clinicians in training novice surgeons, teaching activities and surgery planning. Moreover, it has been proven that a touchable 3D model allows the patient to better understand the surgery and to give informed consent with higher awareness [4]. Currently, external companies provide most of the 3D-printed products to hospitals [5]. Only a dozen 3D-printing services have been fully internalized inside the hospital worldwide [6], to bring the supplier closer to the beneficiary, to involve physicians in the printing process, and to reduce production times and costs.

An intense communication flow between physicians, engineers and radiologists takes place to produce the artifacts. It requires to be properly formalized in order to guarantee the adequacy of the artifacts, to supply the products promptly, to maintain the service economically sustainable and, ultimately, to improve the quality of care.

To our best knowledge, there is only one commercial tool that supports and facilitates the flow of information between technical staff and physicians in internalized 3D-printing services, i.e., the Materialise Mimics (Materialise, Leuven, Belgium). However, this tool only works with Materialise proprietary file formats, is a closed product that cannot be customized to the needs of any specific hospital or laboratory, and is expensive (it costs more than 10 k€ per year). These factors can prevent it from spreading in practice. In particular, the inability to process the most common segmentation and 3D virtual file formats represents a limiting issue.

This work presents a novel open web platform that supports the flow of information and the collaboration between the operators involved in the design and production of patient-specific 3D-printed artifacts inside the hospital. The platform, called 3DSCT which stands for "*3D: See, Comment and Treat*", has been applied and tested in a real internalized 3D-printing service, i.e., the 3D4Med lab (www.3d4med.eu) inside the *IRCCS Policlinico San Matteo* hospital, Pavia, Italy. It is currently the only fully internalized 3D printing service inside a hospital in Italy and represents a reference model for other centers that could be opened in the future.

2. Key Functionalities of the 3DSCT Platform

The 3DSCT platform is intended to act as an interface between three categories of users, who are essential and complementary for a 3D-printing service inside the hospital:

- Physicians, who usually perform the surgery, define the specifications of the 3D-printed artifact, and interact with the patient;
- Engineers and technicians expert in biomedical image analysis and segmentation, 3D modeling and 3D printing, who produce the artifact;
- Radiologists, who acquire the images to meet physicians' and engineers' requirements, and provide information for interpreting images and support for segmenting them.

The process of producing a patient-specific 3D-printed artifact begins when the physician asks for a new project and provides details about the case. In response, the radiologist acquires the images of the district of interest. Then, the engineers receive the images. It follows a meeting to discuss the details of the project and the specific physician's requirements, who also provides support to engineers and technicians in reading and understanding the anatomical districts in the images. In case images are inadequate, e.g., of low quality, a new set of images is required. After the meeting, the 3D-printing service develops the 3D virtual model, involving the physician if needed. Once completed, the virtual model is checked by all operators before printing, and then sent to a suitable printer among the available ones.

Traditionally, this workflow consists of recurring meetings to discuss the progress of the projects. This approach can be improved by interactively using a shared platform, which facilitates interactions and speeds up decision-making.

Key requirements reported in the literature [7,8] for a successful integration platform have been taken into account while developing the 3DSCT platform: *i)* high usability, via an intuitive interface; *ii)* collaborative design to share information and comment on the project; *iii)* strong sense of structure and navigation, so that users know where they are; *iv*) simple and quick access the web pages. Moreover, following Berlyne's theory [8], the trade-off between complexity and communication effectiveness has been considered, avoiding an excess of links on the web pages, which can lead to information overload and a less intuitive and usable platform.

Finally, it is worth pointing out that the development of the 3DSCT platform in close contact with the 3D4Med lab allowed us to adapt to their needs, meet their specific requirements, and test each component in the best possible way [7].

3. Methods and Tools

The 3DSCT platform has been designed to streamline the design and production process described in the previous section. It has been implemented using Microsoft Visual Studio Code, enclosing .js scripts and HTML pages with the relative CSS formats. In particular, VTK.js has been exploited to develop a web 3D viewer for DICOM medical images and 3D virtual models. The adoption of this solution was fostered by different factors: *i)* the availability on the market of 3D tools for web applications; *ii)* the support guaranteed for different types of devices, e.g., personal computers and tablets; *iii)* the limited usability of a smartphone app with respect to a web platform, due to the small screen size.

Data storage is handled by MySQL Workbench. The connection between the platform and the database was accomplished with LoopBack 4 (www.loopback.io).

The right to access the platform is given to engineers/technicians, physicians and radiologists according to their role. In other words, web pages and visualized information vary based on the type of user. Moreover, each physician and radiologist can only access the projects of their patients.

The whole web platform is based on the standard HTTP protocol for data exchanging (Figure 1).

Below, we provide some insights into the main aspects of the platform.

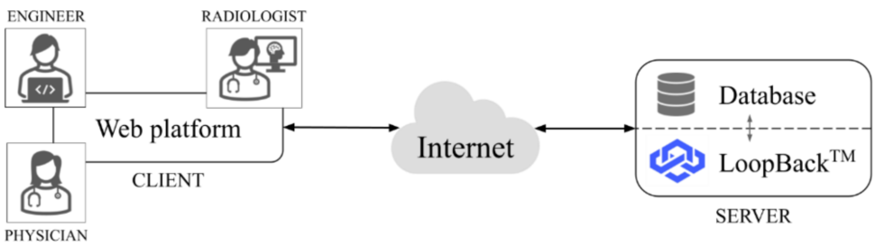

Figure 1. The basic software architecture of the 3DSCT web platform.

3.1. Data Management

All data are associated with an entity, the most important of which is the entity *project*. Each project must necessarily be associated with an existing entity *patient*. Any number of *projects* can be associated with a *patient*, while each *project* must be associated with one and only one *patient*. Similarly, each project is associated with a *physician* and a *radiologist*.

If an entity does not exist yet, a suitable user can easily create it by filling out a dedicated form that includes the attributes associated with the entity. For example, in the case of a *patient*, the most important attributes are: name and surname, unique identification code and birthdate. In the case of a *project*, they are: brief content description, project due date, exam date, hospital department, anatomical district, and associated physician.

In addition to this list, a further attribute, called *status*, is automatically associated with a new *project*, and subsequently updated. Its values represent the progress of the *project*, summarized in the following steps: project initialized; DICOM images uploaded, 3D virtual model development; project discussion and eventual model changes; approved model to be printed; 3D-printed artifact ready. Moreover, other values of the *status* consider the cases in which the *project* is sent back to a previous workflow stage, e.g., when a new set of images is required. The *status* aims are to keep track of the production stage of each project, to activate specific status-dependent functionalities on the web pages, and to enable the access to different operators based on the work progress.

3.2. Differentiation between User Types

When a user is registered, a role is assigned to him/her (*physician*, *radiologist*, or *engineering*/*technician*). To increase the efficiency of the process, the web platform has been designed with different pages and functionalities based on the role of the user who logged in. The rationale behind this choice is the fact that the three user types have different tasks in the *project*. This increases the accessibility of the tool, in accordance with the Berlyne's theory [8].

For example, the role of the *radiologists* is limited to the first stages of the workflow, up to the definition of the 3D virtual model. They upload the DICOM images and support engineers and technicians in segmenting them, especially in the case of structures that are difficult to segment. Then, there is no need to involve them in printing the artifacts.

Figure 2. The 3DSCT homepage.

3.3. Interfaces

The graphical interface is a crucial aspect of the 3DSCT platform, especially as it deals with large amounts of data and different users, because it allows a better and more intuitive search for one specific project or attribute.

The 3DSCT platform is built around a homepage, whose access is guaranteed through a login page.

In order to make the experience more user-friendly, the homepage allows the users to reach an existing *project* in three ways: through the list of all *patients* (item A in Figure 2), the list of all *projects* (B), and through a search by fields (C), which allows filtering the projects based on the keywords typed by the user relating to the *status*, the department or the anatomical district. Finally, it is possible to access a list of Frequently Asked Questions (D), and to logout (E).

Figure 3 displays the core interface of the 3DSCT platform, which shows the designed 3D virtual model, if already available and some relevant information (e.g., the identifying data of the *project* and the due date), as well as the items that facilitate the exchange of information with the physicians. Moreover, in the top right panel, the users have access to a gallery showing the pictures of the artifact once printed.

In particular, by means of buttons, this interface allows to upload the 3D model, to confirm the end of the *project* or delete the *project*, to upload or download the DICOM images, and to displayed them by means of the buttons below the 3D viewer.

The core interface is only accessible to physicians and engineers/technicians. Both of them can type a comment in the dedicated text box about the current 3D model. Notes are displayed in chronological order and visible to all users, together with the time and date of submission and the identification of the author (automatically taken from the login data). When the physician and the engineer/technician agree on the latest model update, any of them can close the project by clicking on a dedicated button; this automatically disables all the options that allow further modifications of the *project*. Nevertheless, a closed *project* it is still accessible from the list and through a search by fields, and it can be reopened by the system administrator in the exceptional case of rework required after closure.

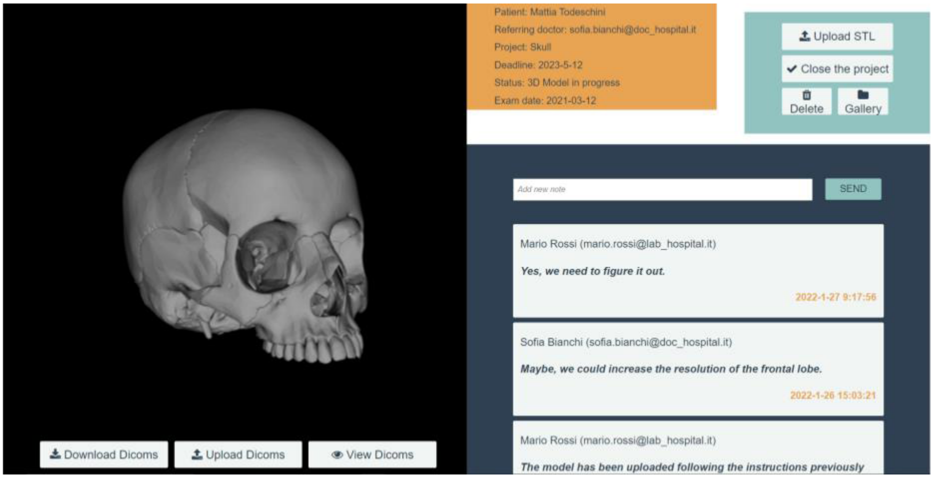

Figure 3. The 3DSCT core interface with 3D virtual model, list of project identifying data, navigation buttons, textbox for typing new comments, and list of previous comments.

4. Application of the 3DSCT Platform to a Real Case

The 3DSCT platform has been applied to the real case of the 3D4Med lab.

This lab was created to integrate 3D-printing technology into the daily clinical activity of the hospital, thanks to the collaboration between the General Surgery II of the *IRCCS Policlinico San Matteo* and the Department of Civil Engineering and Architecture of the University of Pavia. Since its inauguration in 2018, the 3D4Med lab has treated about 250 clinical cases from different clinical-surgical specialties, e.g., abdominal surgery, cardiology, cardiac surgery, neurosurgery, orthopedics, otorhinolaryngology and maxillofacial surgery, thoracic surgery, and vascular surgery.

The lab is equipped with all the hardware and software necessary to satisfy a wide range of requests, ranging from the production of patient-specific anatomical models for pre-operative surgical planning to the development of instrumentation for individual patients and phantoms for the simulation of surgical procedures, largely employed for educational purposes. Moreover, it is located inside the hospital in a strategic position to facilitate communication and interaction between surgeons and engineers.

After development, the prototype platform was tested and validated by the staff of the 3D4Med lab, who evaluated the web solution positively and confirmed its potential in supporting the design and production of 3D-printed artifacts following the requests of doctors.

In the near future, the prototype will be embedded in the hospital management system and picture archiving and communication system (PACS), in compliance with all security protocols of such systems, to allow its daily use in the practice of the 3D4Med lab inside the *IRCCS Policlinico San Matteo*. This integration will also allow to automatically import the attributes of a *patient* from the PACS when a new *project* is created and associated to him/her.

5. Discussion and Conclusions

The 3DSCT platform has been developed to enhance communication in an innovative clinical context. It represents an open, practical and easily integrable solution, which makes the whole design and printing process more efficient from the request of the project, through its development, to the deployment of the 3D-printed artifact. Thanks to this platform, it is possible to reduce the overall lead time of each item and decrease the waste of time for the involved operators.

In particular, the comment-exchange method included in the platform allows the traceability of the communication, keeping track of the steps of each project over time. This makes the acquired knowledge available for future projects that share some characteristics with those already closed.

Thanks to the integration with the hospital management system, data security is no longer a problem as the 3DSCT platform will be added to systems already developed in compliance with security and privacy (GDPR) protocols.

Being a web platform, it can be continuously improved and extended in an agile way, adding new features in response to the problems that will arise during practical use. Indeed, the platform is easily renewable over the years with simple updates of the HTML and .js codes. Possible extensions of the platform will involve several dimensions.

To make the process even leaner, a worthwhile addendum could be a notification mechanism (relying on SMS or e-mail) when the status of a project changes, a user posts a new comment, or an engineer updates the 3D virtual model. This would allow the users to have real-time updates of the process, preventing oversights and delays, especially when working on many projects in parallel.

The creation of a *patient* account with limited access to his/her 3D virtual model and pictures of his/her printed artifact would be a helpful upgrade. For example, it would further increase the benefits of a preoperative informed consent supported by viewing the patient-specific 3D virtual model.

Finally, the platform could be embedded with a scheduling tool, which exploits the information on all active projects and available 3D printers to provide an optimal production plan that reduces delivery delays and underutilization of printers.

References

[1] Machon M, Knighten ML, Sohal J. Improving clinical communication and collaboration through technology:: a benefits analysis for nurse leaders. *Nurse Leader*. 2020; **18**(5): 481–6.

[2] Wang EH, Zhou L, Chen SHK, Hill K, Parmanto B. An mHealth platform for supporting clinical data integration into augmentative and alternative communication service delivery: user-centered design and usability evaluation. *JMIR Rehabil Assist Technol*. 2018; **5**(2): e14.

[3] Weiner JP. Doctor-patient communication in the e-health era. *Israel Journal of Health Policy Research*. 2012; **1**(1): 1-7.

[4] Pietrabissa A, Marconi S, Peri A, Pugliese L, Cavazzi E, Vinci A, et al. From CT scanning to 3-D printing technology for the preoperative planning in laparoscopic splenectomy. *Surg Endosc*. 2016; **30**(1): 366–71.

[5] Lanzarone E, Marconi S, Conti M, Auricchio F, Fassi I, Modica F, et al. Hospital factory for Manufacturing customised, patient-specific 3D anatomo-functional models and prostheses. In: Tolio T, Copani G, Terkaj W, eds. *Factories of the Future: the Italian Flagship Initiative*. Springer, Cham 2019; pp. 233-54.

[6] Marconi S, Mauri V, Negrello E, Ghiara M, Peri A, Pugliese L, et al. The experience of a clinical 3Dprinting laboratory: current and future perspectives. *Minerva Orthopedics*. 2021; **72**(4): 395-406.

[7] Grebner C, Norrby M, Enström J, Nilsson I, Hogner A, Henriksson J, et al. 3D-Lab: a collaborative web-based platform for molecular modeling. *Future Med Chem*. 2016; **8**(14): 1739-52.

[8] Geissler G, Zinkhan GM, Watson RT. Web home page complexity and Communication effectiveness. *J Assoc Inf Syst*. 2001; **2**(1): 2.