Doctors, Patients, and Service Providers:

A cloud-based approach for managing healthcare processes

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***Abstract*—The ability of an eHealth system to empower and support doctors in undertaking healthcare processes and adapting them to the specific needs of their patients is key for its success. In this paper, we present a cloud-based approach for this type of eHealth systems, and consequently encourage their proliferation. First, we discuss a new healthcare business model that emancipates doctors from their reliance on technical assistance, and facilitates their cooperation with healthcare service providers. Then, we introduce a conceptual model of healthcare processes that allows doctors to understand, program, and upkeep them easily. We illustrate how both these components constitute a basis for cloud-based eHealth systems by discussing the development of a prototype implementation. Finally, we show how the prototype can be integrated in existing workflows by discussing a contextual analysis conducted to guide this integration. We conclude by discussing our results.**

Keywords-eHealth; Business Process Management; Cloud Computing

I. INTRODUCTION

Despite the exponential growth in information and communication technologies (ICT) and their pervasive integration in different domains of human enterprises, current ICT solutions do not generally address the needs of today's modern medicine [1]. In particular, in the context of the rise of web-based social networking, Service-Oriented Architectures (SOAs), and cloud computing, little support for translating healthcare processes to the web, and managing remote doctor-patient relations is provided. In order to support this translation, there is a need to develop a new approach for modern healthcare systems that facilitates the sharing of information, modules, and services, as recommended by Valeri et al. in their extensive study conducted for the European Commission for Health [2].

Currently, cloud-based healthcare services made available by third-party providers are growing in number and maturity [10]. These services have an important potential to improve overall healthcare delivery on the web, but they require appropriate Service-Oriented Architectures (SOAs) that stimulate and support their integration into customized healthcare processes. These SOAs enable the creation of cloud-based systems that could empower doctors to create diagnostic, medical, and monitoring processes from third-party services available in the cloud, and publish them on the web for the benefit of their patients without the help or direct intervention of ICT experts. This would allow doctors to exert a more elaborate control over their patients' web experiences, and adjust their processes according to the patients' profiles (e.g. older people, chronically ill, handicapped, or children). As a result, now the patients could execute the personalized processes designed by their doctors more confidently. This direct doctor-patient interaction will allow service providers to study and understand how both doctors and patients use the services they offer. Consequently, service providers could alter, improve, or adjust their services based this essential feedback.

We identify two main requirements for cloud-based eHealth systems: first, they should implement an adequate business model that permits stakeholders (doctors and service providers) to capitalize on their investments, and guarantees a long-term sustainability to build up its success [2]. Second, the systems must support and empower doctors, patients, and service providers, in performing their roles independently. In particular, doctors should easily create healthcare processes and customize them for their patients, patients should use them with confidence and ease, and service providers should create and adjust adequate services relevant to the needs of both doctors and patients.

In this paper we introduce an approach fulfilling these two requirements of cloud-based eHealth systems. It consists of two main components: an eHealth business model designed to emancipate doctors from IT consultants and software developers, and facilitate their collaboration with service providers; and an intuitive conceptual model for healthcare processes that enables doctors, patients, and service providers to understand them easily and evenly. Both components provide a foundation for the development of cloud-based eHealth systems and promise to facilitate more and better ICT integration into healthcare.

In the following section, we discuss some related work before introducing a new cloud-based business model for eHealth that supports doctors in managing their online healthcare processes, and service providers in tapping into the eHealth market. Then, we propose a conceptual model of healthcare processes conceived as a mediation tool for

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forging interaction and cooperation between doctors, patients, and service providers. We then present VirtualClinic, a prototypical system designed to illustrate the feasibility of our approach. Finally, we discuss a contextual inquiry conducted at a local clinic to evaluate if VirtualClinic can be integrated in existing workflows and understand how this integration should be effectuated.

II. RELATED WORK

Currently, apart from the challenges discussed earlier, the development of eHealth systems is hindered by several barriers proper to the eHealth sector, such as those stated by Sittig et al. [3].These challenges need to be overcome to develop such architecture and consequently integrate ICT technologies in healthcare successfully. Several cloud-based approaches exist, such as the integrated eHealth Living Labs introduced by Mazurek and Stroinski, which is a platform with application areas from disease research, through treatment organization, to remote consultations, among others [1]; and Rolim et al. for remote monitoring of patients through sensor-based data collection [4]. However, the existing approaches do not provide doctors with the required control over the processes, nor facilitate the incorporation of a wide range of third-party services.

In addition, eHealth business models are still immature and specifically not adapted for cloud computing environments[2]. However, it is possible to formulate new adequate models by relying on the conceptual business architecture proposed by Motahari-Nezhad, Stephenson, and Singhal for cloud computing in [5], which addresses the business context (in this case, eHealth), the support for non-technical profiles, the lifecycle of business processes, and third-party services.

III. A CLOUD-BASED BUSINESS MODEL FOR EHEALTH

In general, business processes should follow an iterative agile lifecycle that permits them to keep evolving and thus adequately answering the changing requirements of their users [6]. In healthcare, doctors can easily devise and personalize the onsite diagnostic, medical, and monitoring processes of their patients, but to the extent of our knowledge, there are no available tools for supporting doctors in developing and maintaining these processes when they are transposed to eHealth systems. Doctors still need external technical support, making difficult to follow the agile lifecycle.

This situation was investigated by conducting a six-month dialogue with three Spanish service providers for eHealth and two leading hospitals in Barcelona. This revealed the characteristics of the classic business model (figure 1) that forms the backbone of current practices in the Spanish sector. Currently, in order to design, develop, and publish online healthcare processes, doctors first need to ask for the help of IT consultants to define these processes in a standardized business process notation (such as BPMN [7]), and later to manage their publication on the web. Then, software developers would implement the processes using their development frameworks. The developers can incorporate third-party services in the processes, but this is usually hindered by the lack of interoperability between the designs of these processes and third-party modules [8].

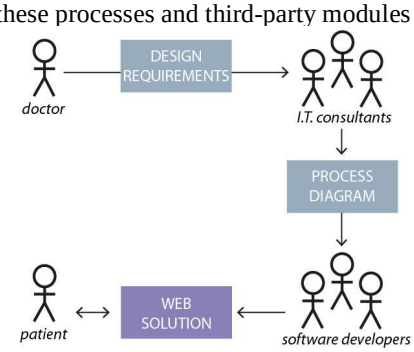

Figure 1. Current business model of the Spanish eHealth sector

The current business model makes doctors heavily dependent on IT consultants and software developers in their quest to provide online healthcare processes for their patients. This requires a hefty dialogue between doctors, IT consultants, and software developers, and therefore increases the risk of losing knowledge during the transition between requirements and design, especially for the design of complex healthcare processes that accommodate various alternatives in the same patients' profile. Similarly, upgrading the resulting healthcare processes to address new requirements (e.g. to cover a new chronic illness, or to introduce a novel memory enhancement service for Alzheimer) also has an important cost. Furthermore, medical knowledge about patients is complex and may be difficult to capture and assimilate by IT professionals.

This complexity leads to centralized solutions (at the level of hospital or larger) that seldom account for interoperability with third-party services and usually do not capture the rich practice of doctors. The maintenance and updating of these centralized solutions is heavy, complex, and very expensive.

The cloud-based model proposed (figure 2) can eliminate dependencies between doctors and technical profiles, improves the doctor's control on the patient's experience, and streamlines the management of healthcare processes. It also provides a platform for service providers to share their services more efficiently. In addition, it creates a more direct and trustworthy relation between patients and their doctors.

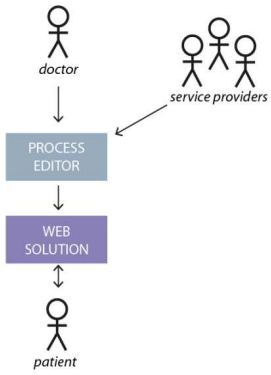

Figure 2. A proposed cloud-based business model

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The works of Motahari-Nezhad et al. provide a framework for applying cloud-based business models to eHealth cases by considering the roles of three main actors in healthcare processes: doctors, patients, and service providers. Doctors compose these processes from a pool of available services and customize them in order to address the specific needs of their patients, including personalization. Service providers offer the pool of generic healthcare services that could be configured and personalized to befit different healthcare processes. The services are defined in a generic way that makes the management of healthcare processes more modular and dynamic by enabling the reuse of same services in several distinct processes. This guarantees a larger usage for the services, and therefore increases their economical feasibility and encourages service providers in identifying potential markets for the services they offer. Patients interact with the processes proposed by their doctors through the web without interference from service providers. However, the success of this model rests on having the required services available in the cloud, and on abstracting the technical complexity of process management from doctors in order to allow their intuitive modeling and management. This is addressed in the following section.

IV. A CONCEPTUAL MODEL OF EHEALTH PROCESSES

The functional requirements of cloud-based eHealth systems that empower doctors in managing healthcare processes independently have been defined and studied by Beyer, Kuhn, and Indulskain [9]. They found that the technical and technological complexity associated with business process management represents one of the largest barriers for the direct involvement of non-technical profiles (such as doctors), and therefore should be reduced. Doctors do not have the required knowledge to program processes and therefore can only rely on non-technical paradigms to manage them. Therefore, they cannot utilize the current standardized notations for designing and implementing business processes (such as BPMN). Hence, we propose the following conceptual model to encapsulate the complexity of business process management in order to facilitate the involvement of non-technical profiles, especially doctors, in managing healthcare processes.

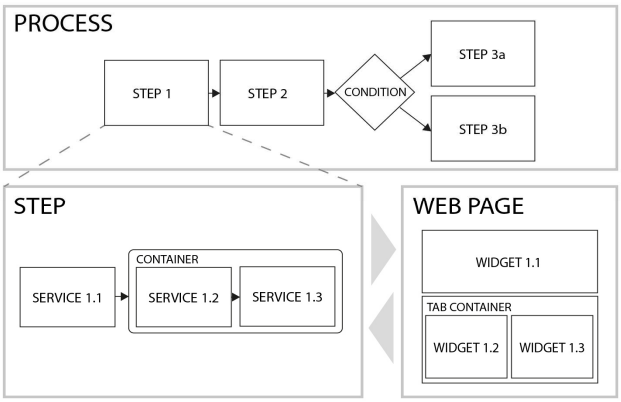

Figure 3. The proposed healthcare process model

This model of healthcare processes has formulated by conducting iterative focus sessions with stakeholders (doctors and service providers), computer scientists, and graphical designers. The objectives of these sessions were to seek a convergence between the different mental models that represent the profiles involved with any cloud-based eHealth system. For this purpose, several different eHealth scenarios were discussed, analyzed, and designed collaboratively (e.g. medical consulting, remote assistance, and follow-up on chronic patients). Figure 3 shows the components (process, step, condition, service, widget, and page) of the resulting model. They are explained in the following.

A. *Process*

The process represents an entire healthcare procedure. Doctors usually manage a variety of processes tailored according to needs of their patients. These needs differ according to the patient's profile and usually evolve in parallel with the evolution of medical practices and treatments. These processes can be published online as a set of linked pages, each hosting one or several components that patients interact with. The process has specific start and end, and several possible routes may exist to execute it from start to end.

B. *Steps and conditions*

A process may be composed of one or several steps. Each step addresses to a specific segment of the healthcare procedure, and groups many atomic actions that correspond to a given objective (e.g. take an appointment, measure and communicate your blood pressure, contact medic and describe symptoms, etc…).

Conditions are logical statements that define bifurcations that processes may have. These conditioned bifurcations allow the process to be flexible and able to respond to several variations of the same patient profile. For example, a condition is used to differentiate between patients with urgent issues that need immediate teleconferencing with their doctor, and those that only require an appointment, allowing the same eHealth process to attend to both cases.

C. *Services*

In essence, a step is an encapsulation of linear sequences of healthcare services connected together to achieve the corresponding segment of healthcare procedure. Services are cloud-based resources offered by service providers. Each represents an indivisible action that users may perform inside a step (e.g. measuring your temperature, selecting an appointment date, etc…). Services are collocated in steps sequentially.

D. *Widgets and web pages*

Services may require user interaction. Widgets are the graphical user interface of these services. Each service may have a single widget, but these widgets may have several interface modes.

In essence, web pages represent the patients' view of the process. They are linked according to the order of the corresponding steps in the process. On the web, each web

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page represents a single step of the process. It composed of the widgets that represent the services of the corresponding step. The widgets are collocated vertically on the page in the order of their corresponding services. When services are grouped non-sequentially, the corresponding widgets are presented in a tab-container on the web page.

E. The process dataflow

According to the model, each step in the process requires a set of input data and generates a set of output data that feeds further steps. Similarly, each service requires a set of input data and generates a set of output data as a response. This output data may be used as an input data for further Services inside the same step. In addition, this data is transmitted along the process and can be used as data input for services. This data can be generated by user interaction with widgets and medical sensors, or retrieved from databases connected to the services.

EHealth systems usually have a rich dataflow of medical and personal information of sensitive and private nature. This information should be securely protected to avoid incidences that can affect the public trust in online healthcare systems. This information should only be revealed to people with legitimate access rights, and otherwise encrypted especially when flowing between cloud components.

F. Evaluating the Process Model with Potential Users

The model has been collaboratively developed by a group of nine persons representing the three main profiles (doctors, patients, service providers). In order to evaluate the intuitiveness of this model, a two hours session was organized with sixteen subjects with no experience in business process modeling, but with knowledge about user-oriented design. The process model was briefly introduced to all the participants, then each one was asked to design healthcare processes for a given scenario by using the model. Finally, the participants were asked to fill a questionnaire about their experience, and informal interviews were conducted with each of them.

The results of these activities show subjects easily understand the model (only one participant did not fully grasp the model components). The subjects found the model to be highly intuitive, and used it to design the required healthcare processes accurately (defining different processes and their steps, selecting the proper services, and connecting all components to insure a correct dataflow).

V. VIRTUALCLINIC: A CLOUD-BASED EHEALTH SYSTEM

In order to assess the feasibility of using both cloud-based business model and the healthcare process model introduced in the design of eHealth systems, we have designed and implemented VirtualClinic, a prototype system for remote diagnosis and medical assistance. It consists of a SOA that permits service providers to offer healthcare services in an interoperable manner, allowing their incorporation in customized healthcare processes. The SOA also manages the publication of these processes on the web and the interaction of patients with them. In addition, the system includes a tool that doctors use to compose and manage healthcare processes. The SOA implements the principles of a cloud-based business model for eHealth, and the tool implements the healthcare process model.

A. A Cloud-Based Service Oriented Architecture

The system architecture is designed to automate the composition and publication of online healthcare processes in a cloud environment. It is composed of a core platform hosted on the system server and three different client modules, each hosted on a corresponding client terminal (figure 4). The core platform design is inspired from that of BPEL engines where a server-based platform controls the execution of the processes. This platform incorporates three main modules: the communication module, the workflow engine, and the service repository.

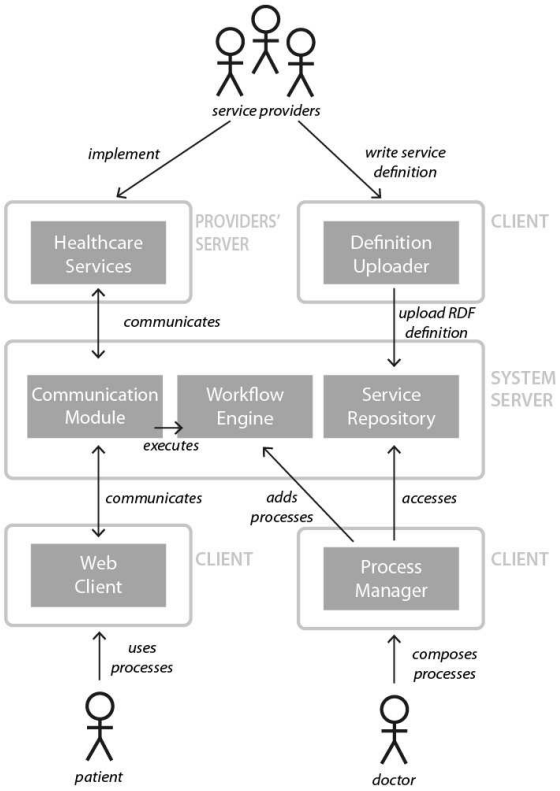

Figure 4. A SOA for eHealth systems

Service providers use their own client on their terminal to add new services to the service repository. The client interface is an online form that generates a standardized RDF definition for each service. Doctors make use of their process manager to compose healthcare processes from these services. The workflow engine compiles and executes the composed processes, and the communication module generates the corresponding web pages, which are accessed by the patient client. The communication module also manages the sending of messages between services, and supports the exchange of information between the process executing on the workflow engine and the patient client,

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enabling patients to interact with the processes a step at a time.

B. A Doctor's Tool for Managing Healthcare Processes

The process manager tool is designed to empower doctors in managing healthcare processes by using the process model to represent them. It addresses the functional requirements as defined by the doctor's role in a cloud-based eHealth system. The tool has two interface modes: one for creating and managing healthcare processes (figure 5), and another for composing the process steps from existing services (figure 6).

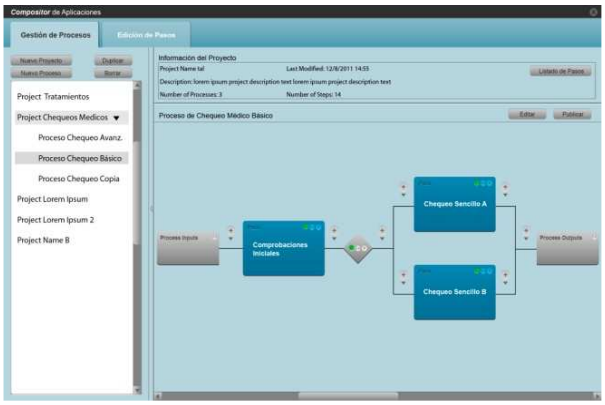

Figure 5. The process manager interface.

Figure 6. The step editor interface.

Doctors can compose a given healthcare process by creating and ordering its steps. In general, the steps are sequentially ordered inside the process, but doctors can define different execution paths by arranging several steps in parallel. This is achieved by introducing a condition in the process that evaluate the output of the previous step in order to decide which of the subsequent parallel steps is the adequate one in the course of the process execution.

The steps are composed from existing services by using the step editor, which is access from the process manager. A browser assists the doctors in searching for and exploring healthcare services available in the repository. Selected services are integrated in the step sequentially, but services can be grouped into service containers. For each integrated service, its data input is automatically connected to the output of its antecedent service, and doctors can edit and modify this linkage. Services are ordered vertically on the corresponding web page, and grouped services are ordered horizontally in tab containers.

C. Executing a remote asistance scenario

VirtualClinic revolves around the scenario where a doctor wishes to remotely provide general medical assistance to two different types of patients: fairly healthy and chronically ill patients. The doctor needs to reduce congestion in the clinic and the patients would like to reduce the travels they effectuate to receive healthcare. Fairly healthy patients only use common eHealth services (e.g. inquiring about their medical history, checking the calendar of consultations, and conferring online with their doctor). Chronically ill patients require a wider more specialized range of services (e.g. checking their vital signs with sensors, sending this data to their doctor, and inquiring about medications and newly developed symptoms). They also might require specific services in accordance with their illness (e.g. Alzheimer patients require memory exercises).

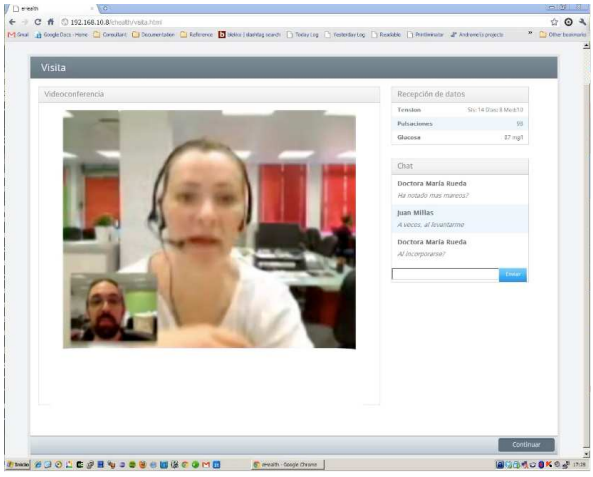

Figure 7. Patient using the remote asistance service

The design and implementation of the VirtualClinic architecture sustain this scenario from a technical stance. The service repository contains a number of general cloud services by default (e.g. registration, billing, calendar, maps, social network services, etc...). In addition, service providers added several healthcare services, including a remote assistance service (figure 7), an electronic prescription service, and a drug delivery service. Given this pool of services, three distinct healthcare processes were created with the process manager and published on the web. One process was dedicated for taking appointments or conferring with a medic for urgent matters; another process allowed chronic patients to renew and update their prescription, and order their medication; the third process centered on the remote diagnosis of older patients. In essence, VirtualClinic provides a proof of concept that illustrates how cloud-based

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systems can be engineered to facilitate both the composition of customized healthcare processes and their execution.

VI. INTEGRATING VIRTUALCLINIC IN REAL SETTINGS

The VirtualClinic as a proof of concept represents a positive assessment of the feasibility of cloud-based eHealth systems. We studied its deployment in a local clinic in order to assess its compatibility and adaptability to real-world settings.

A local clinic (subsidiary of Munich Health, a leading European health insurer) specialized in work-related accidents treatment and prevention was chosen as the test bed for this study. This typical clinic is part of an intricate network of private healthcare services in Spain, which includes private hospitals, laboratories and diagnostic centers. This network represents a prime customer base for commercial healthcare service providers, including the emergent eHealth services.We conducted a contextual inquiry in the local clinic, which included interviewing the different relevant profiles, understanding the workflow among them, and the systems they rely on to manage their work. Its results identify the manner by which VirtualClinic should be integrated.

A. *Identifying the workflow at the local clinic*

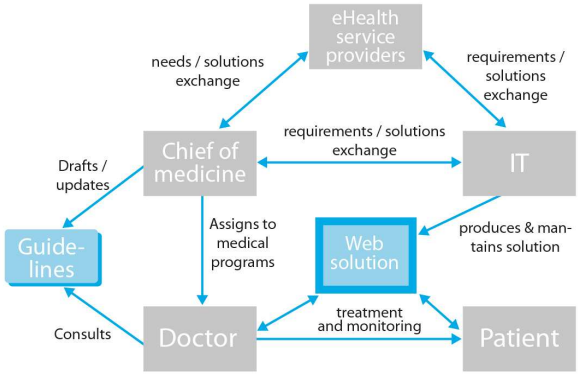

Figure 8. The current workflow in the local clinic

Five main profiles are considered relevant in our context: the *chief of medicine* drafts and updates the clinical guidelines that doctors follow, and assign doctors to specific medical programs (e.g. prevention of aspiratory diseases in the workplace, or treatment of head injury and trauma); the *doctors* (a total of 18) keep a direct and periodic contact with *patients*, and often use the web system to assign them visits, reminders, and exercises. The web system is a doctor/patient interface;*patients*(more than 2,000) use the systemto access relevant information and services from their homes; The*IT department* (5 IT experts) developed the web system and services and upgrades it according to the directions of the chief of medicine; in addition, third-party *eHealth service providers* sell off-the-shelf solutions to the clinic and service them afterwards in collaboration with the IT department, and discuss new products with the chief of medicine.

The workflow associated with these profiles is drawn in figure 8.It isolates the section of the clinic workflow relevant to the deployment of cloud-based eHealth systems. It is typical of contemporary clinical workflows, with a strong initiative in eHealth and telemedicine.

B. *Understanding the views of different profiles*

The interviews with the chief of medicine, a doctor, and two IT experts focused on the potential of adopting a cloud-based model, its advantages and disadvantages from the point of view of each profile.

The chief of medicine requires a more dynamic way to manage the creation and upgrade of clinical guidelines, and include third-party services in them. He views cloud-based systems a necessity as the relation with patients becomes more digitized. The doctor does not wish to rely excessively on remote services nor sees alternatives to meeting regularly with patients, however she recognizes the potential of web-based services in therapy and rehabilitation.The doctor also considers videoconferencing a positive and efficient approach for support and emergencies. The IT experts are capable of building and handling complex systems, they think cloud-based systems are good and advanced solutions but they raise concerns about data security. Adopting a cloud-based infrastructure allows them to expand their system easily by relying on third-party components.

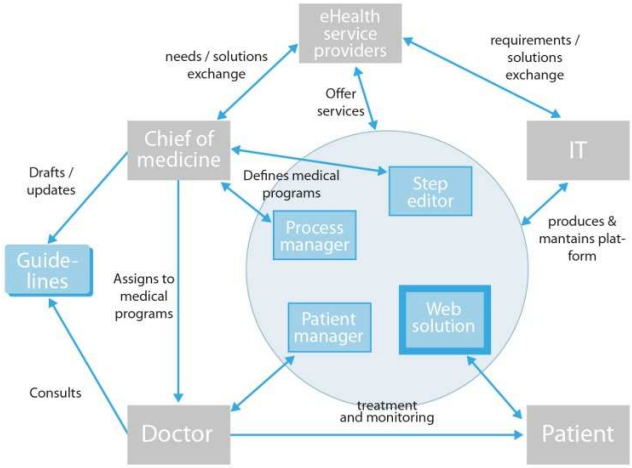

Figure 9. The integration of VirtualClinic in the workflow

C. *Integrating VirtualClinic*

The integration of VirtualClinic in this workflow should preserve the current structure as much as possible and avoid disadvantaging any profile. The system should also be integrated with other existing tools (e.g. the patient manager that doctors use to maintain digital dossiers).

For this purpose an integration proposal has been conceived, discussed with the different profiles and adjusted to provide a good fit. This integration (figure 9) is currently ongoing. According to it, the chief of medicine uses the process manager to draft new processes as clinical guidelines; future upgrades will look into unifying both digital and printed systems. The doctors use an integrated patient manager (currently under development) to assign the processes designed by the chief of medicine to their patients

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"step by step". The IT department manages the entire system architecture and mediates the participation of service provides. These can now benefit from a broader opportunity to sell their services. The patient experience also benefits from the new services, as the system is not design to replace any existing procedure.

VII. DISCUSSION

Our experience with VirtualClinic illustrates the viability of cloud-based solutions for eHealth applications. It shows how the technical complexity of these systems can be encapsulated by making the involved profiles more independent and supporting each in performing its role. Doctors assume control over the management of healthcare processes, patients benefit from more personalized and trustworthy procedures, and service providers sell their services in the cloud.

The contextual inquiry conducted at a local clinic and the subsequent integration (undergoing) of the VirtualClinic demonstrate that these systems can be adopted as a major transition step toward a cloud-based business model. They also simplify the workflow by making each profile more independent and empowered: the chief of medicine can manage the guidelines with ease and also integrate services from external providers. Doctors have more access and control over these services. In addition, the IT department no longer needs to maintain direct relation with the chief of medicine.

The approach proposed in this work can be applied in other domains where non-experts require the help of technical profiles in managing their business processes. In particular, it is currently being applied in an eCommerce scenario where a t-shirt manufacturing company wishes to allow customers to design, customize, and order their own t-shirts on the web. In this scenario, one of the interesting challenges is to empower marketing directors to constantly create and publish sales campaigns on the web sites, including social networks.

VIII. CONCLUSION

Current eHealth business models require a constant involvement of IT professionals to create and maintain online healthcare processes. The cost of managing healthcare processes in accordance with these models is elevated, and its efficiency is reduced. In this work, we evaluated the use of a cloud-based business model that simplifies the management of healthcare processes, dispenses this task directly to the doctor, and facilitates the incorporation of third-party healthcare services. Consequently, it allows for a more direct doctor-patient relationship through the web.

A conceptual model of healthcare processes is introduced to address the interaction requirements that the cloud-based business model entails. This process model allows doctors to assume control over the creation and customization of healthcare processes and minimizes their technical complexity. We evaluated the feasibility of our approach by implementing VirtualClinic, an eHealth system design for remote assistance. In addition, a contextual inquiry was conducted at a selected clinic to integrate VirtualClinic. The results illustrate how VirtualClinic is being integrated.

This approach also has its limitations. Several important aspects of eHealth systems were not addressed, including data security and privacy issues, which are important due to existing risks and regulations. The services currently used in VirtualClinic do not raise such concerns; however they should be addressed in the near future to include services (e.g. remote-diagnostics) that raise them. In addition, the cloud-based system requires a largeand diversified pool of services to allow a diversity of processes to be created. The quality of the available services also plays an influential role. Nonetheless, the lucrative opportunities inherent in the eHealth sector act as a sufficient incentive for service providers to refine the services they offer. With the ability to monitor the use of their services, service providers can receive essential feedback to improve them. This constitutes the backbone of our future work.

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