VIRTUAL MODELS FOR ARCHAEOLOGY

1. Introduction

In this paper we propose a conceptual framework for the creation and management of excavation projects. As discussed in Section 2.1, archaeological excavations are complex activities involving a number of different organisations and individuals, each having a particular role in the context of the excavation. Organising an excavation can be very complex and time consuming due to the number of parties involved. In fact, «much of any excavation time, and certainly most of that of the site director is really spent not on sophisticated academic thoughts but on organisational matters» (Roskams 2001, 3).

The organisational aspects of an excavation may be crucial for its success, and the effectiveness of an excavation may depend on the interactions between different actors. In a recent project known as the Greyfriars Project (http://www.le.ac.uk/richardiii/), for example, several individuals and institutions joined forces to search for the mortal remains of King Richard III in Leicester. It was known from historical documents that King Richard III died at the battle of Bosworth in 1485, and his body was brought to Leicester and buried in the church of the Franciscan Friary. Neither the building nor knowledge of the exact location of this burial survived to the present day. Philippa Langley from the Richard III Society initiated a search for the burial, and with financial support of sponsors and support of the Leicester City Council as the land-owner, the University of Leicester's Archaeological Services under Richard Buckley undertook excavations in areas that seemed promising.

And indeed, under a city council car park, architectural remains that matched the historical descriptions were uncovered, and within them were the skeletal remains of a buried individual in his thirties with significant skeletal deformations and battle wounds. The discovery of the body was followed by a host of scientific analysis, led by Jo Appleby (an osteo-archaeologist from the University's School of Archaeology and Ancient History) and Turi King (the project's geneticist). Samples were radiocarbon dated, isotope analysis confirmed a high protein diet, and the skeleton's DNA matched of Richard III's maternal line relatives. Last, a facial reconstruction of the king's skull was undertaken. This may be an unusually complex case, yet the way any excavation is organised can determine its success in achieving its objectives.

We advocate the use of a conceptual framework capable of representing the organisational aspects of archaeological excavations to represent explicitly the roles, activities, and interactions among the roles. We contend that our methodology helps in anticipating pivotal critical situations that

may hinder the effectiveness of excavations. Moreover, our approach fosters the planning of an excavation at a fine-grained level of detail which does not only help planning the scientific work related to the project, but also support archaeologists in the selection of participants (building company, scientific analysis, radiocarbon dating, etc.). A strength of the framework is that "organisational" patterns can be reused any time, whilst uttermost flexibility can be retained.

Technically, we use Virtual Breeding Environments (VBE) and Virtual Organizations (VO). These concepts have been introduced in computer science to study the communication and coordination issues emerging from highly dynamic and distributed organizations. More insights on VBE and VO are given in §2.2; here we just give an overview. A VBE specifies the set of criteria according to which some parties establish a long-term collaboration (for instance, archaeologists need to initiate long-term collaborations with local institutions when starting an excavation). A VO can be thought of as a dynamic ensemble of communicating and collaborating entities. Basically, a VO rules the communication and coordination activities of a community (for instance, the preliminary paperwork for an excavation has to be carried out by authorized actors who have to apply some procedures).

A main contribution of our work is to show that VBE and VO are suitable to help in the set up and management of archaeological excavations. Day-to-day logistics may seem routine, but are in fact complex interactions that directly affect the outcome of an archaeological research project; poor logistical organization may result in negative impacts on project results. In this paper we discuss how a more systematic approach based on precise models may help in anticipating management problems as well as in making excavation management a more effective and efficient activity. We also discuss the limits of the approach and suggest possible extensions.

2. Background

2.1 *Archaeological excavations*

Archaeology has long since moved on from its roots in a 19th century gentlemen's pursuit to being a general public concern. The preservation and investigation of heritage has become an important part of identity on a group, nation and global level (e.g. Carman 2002; McManamon, Stout, Barnes 2008; Moore, Whelan 2007). Archaeology is concerned with the human past, which spans from the first stone tools in eastern Africa 3.4 million years ago to the present (Bahn 2000). Activities of past human societies left a variety of traces in the soil and above, including remains of material culture, architecture, or changes in environment and landscape, many of which can

be accessed through excavation and studied. For archaeology as a discipline, excavations remain one of the primary sources of knowledge in the study of the human past; although a variety of complimentary methods and techniques have become available, in the minds of the general public excavation is almost synonymous with archaeology (Derks, Tarlow 2011).

Excavation is not only a complex process in itself; the motives of excavation are equally complex and manifold. Early excavations were driven by the idea of recovering valuable treasures and curious objects; uncovering and documenting the context of these objects became a subsequent concern. Excavations were increasingly carried out to understand the human practices and processes that led to the deposition of material traces in the ground. Notably, archaeology became less concerned with recovering objects and more with the way in which people engaged with materials, artefacts and places in the past. Since the excavation of an archaeological site is simultaneously its destruction (see Lucas 2001 for further discussion), each intervention into sites has to be justified. Today, excavations carried out merely to answer research questions are in the minority. The majority of practical archaeological work is done in anticipation of inevitable destruction of sites, mainly caused by the housing and industrial development and the build-up of infrastructure. Rescue or preventive archaeology is currently most often overseen at a national level (see Bozóki-Ernyey 2007a for an overview of European practices and legal frameworks), but commercial archaeology companies, universities, local museums, local research centres or other public bodies may be employed in the organisation and implementation of excavations.

No universally accepted standard for excavation methods exist. This is partly due to the complex nature of archaeological sites, as each site not only has a unique sequence of stratigraphic units and differential levels of preservation, but also constitutes one of a variety of past structures; these may be classified as settlement, burial and ritual sites amongst others. Excavating the stratigraphic sequence in reverse order to its deposition (Harris 1989) promises the best results to advance our knowledge of the past, but this approach may have to be altered in response to particular challenges. There are a number of excavation guidelines available (e.g. Barker 1993; Biel 1994; Roskams 2001). However, these never replace the experience of a skilled practitioner, who is both familiar with general archaeological principles and the local archaeology.

The archaeologist's responsibility after the excavation of a site lies in the management of retrieved data, publication and dissemination of knowledge. Analyses of finds and samples have to be organized and involve a different set of practitioners with additional sets of skills. Timely publication of site reports and public data access are increasingly required to ensure future funding. The

spending of public money in particular needs to be transparent and justifiable. The sharing of information and collaboration between many different people in the archaeological community provides an ongoing challenge. Today the coordination of collaboration occurs at an *ad-hoc* basis, is often subject to either serendipity or poor outcomes, and encompasses unforeseeable temporal delays; this could be improved by modelling the whole excavation process virtually before it takes place, but keeping the model flexible enough to allow for adjustments during the project.

2.2 *Virtual Breeding Environments and Virtual Organizations*

In this section, we give an introduction on Virtual Breeding Environments (VBEs) and Virtual Organizations (VOs). Roughly speaking, VBEs provide an infrastructure for the dynamic creation and management of VOs while VOs address the need of rapidly forming collaborative environments for different groups of participants who may belong to different actual organizations. A VO yields a common infrastructure for sharing information across the actual organisations. Moreover, a VO:

– enables interactions among its participants,
– disciplines the execution of tasks,
– disciplines the usage of resources,
– specifies policies for accessing resources, and
– regulates the responsibilities of its participants.

VOs are widely used in e-science (e.g., in Grid computing) to support "flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions, and resources" (FOSTER, KESSELMAN, TUECKE 2001). For example, the frameworks developed in projects like Open Science Grid (OSG) and Enabling Grids for e-Science in Europe (EGEE) allow different kinds of institutions and universities to share their resources and rely, when needed, on huge distributed storage and computational power (FOSTER 2006). Resource sharing enables participants to rely on a much bigger usage potential, given that they need very intensive resource usage but only at specific times.

In a VO, participants may engage in collaborative activities (possibly requiring access to shared resources). VOs discipline such collaborations by imposing rules that restrict the access to the resources, specifying specific collaboration processes, establishing authentication and authorization procedures, etc.

The need for creating a new VO typically follows from the emergence of a set of collective opportunities, goals, or interests. BYRNE 1993 defines a VO as an infrastructure that creates a «... temporary network of independent companies, suppliers, customers, and even rivals - linked by information

technology to share skills, costs, and access to one another's markets». This definition underlines two key characteristics of VOs. The first one is the loosely-coupled relationship among participants, whose collaboration is contextual to the specific VO. The second one is the fact that the collaborations have a limited duration. Following Camarinha-Matos, Afsarmanesh 2007, the phases that a VO goes through during its life-time are: preparation, operation, and dissolution.

A new VO is created when a timely solution is needed, and it lasts until such a need has been fulfilled. Because of such dynamism, the management of the life cycle of a VO should be agile. For example, in the preparation phase, it is important that the choice of the parties to include in the VO is supported by a suitable infrastructure. At the same time, it is important that the selected parties are "ready" to engage in the collaboration, in the sense that they are aware of the process of joining a VO (Romero, Galeano, Molina 2008).

A VBE tackles the lack of trust, information, and integration of the parties willing to engage in short-termed collaborations by providing a long-term stable infrastructure in which VO can be created and managed. The aim of a VBE is to increase "chances and preparedness towards collaboration in potential virtual organizations" (Camarinha-Matos, Afsarmanesh 2007). Whereas VOs are short-lived, the life cycle of a VBE is more likely to be followed by a metamorphosis (i.e., progressive modification of long-term goals). The infrastructure provided by a VBE may include precise processes for the formation of VOs, IT infrastructures, catalogues of participants available to take up specific roles/responsibilities, etc.

3. Case studies and models

In this section, we illustrate the applicability of the ideas described in Section 2.2. Namely, we model an environment that supports the long-term management of resources, such as archaeological findings, and the timely creation and management of VOs for excavation projects. We have chosen this case study as the excavation activity is germane to all branches of archaeology. Section 3.1 and Section 3.2 model the VBE and the VO for our case study. We use the graphical notation from Bocchi *et al.* 2009, which is a customization of UML Use Case Diagram (OMG 2011) for modelling VOs and VBEs. This notation uses the abstractions of the service-oriented paradigm in which applications can dynamically compose with external services at run-time, relying on a middleware that supports service discovery and composition. This abstraction is useful in our context, for example to support the assemblage of the VO which may require the involvement (discovery, selection, contracting) of external parties.

3.1 *Setting up an environment (VBE) for archaeological projects*

In this section, we illustrate how to model a virtual breeding environment to support the timely and organized creation of archaeological projects. As a case study, we consider the following scenario:

A consortium of archaeologists from different universities of the Midlands wishes to build a framework to support the timely creation of different kinds of projects, in particular excavations. The framework must support the access to a local set of the resources (e.g., a database of archaeological findings) by the members of the consortium. Additionally, the framework must allow external institutes to access the resources according to pre-defined access upon payment.

According to Bocchi *et al.* 2009, a VBE model may include the following types of actors:

– *resources* (the assets of the VBE),
– *partners* (the persistent members of the VBE),
– *customers* (organizations external to the VBE that may occasionally *use* some services provided by the VBE), and
– *externals* (organizations external to the VBE that may occasionally *provide* a service to some tasks of the VBE).

In our scenario, the long-term aim of the VBE is to manage the access to information repository of the consortium, represented by a resource actor called DataCollection. The VBE has the following partner actors: the archaeology departments ArchaeologyDept, and a finance compartment FinanceComp. Actor ArchaeologyDept represents (i.e., can be instantiated with) any member of the consortium that wants to access the information source. The finance compartment is the entity that finds/manages transactions (e.g. to handle accesses to the data collection from external research institutes that require a payment) and the funds needed for the excavation projects. The customer actor Researcher models the research institutes that are external to the consortium and that occasionally interact with the VBE to access the data collection. Our scenario does not involve any external actor.

The model of the VBE, called ArchVBE, is illustrated in Fig. 1. Each stereotyped stickman corresponds to an actor. The scope (or *boundary*) of the VBE is graphically represented as a box which includes the tasks supported by that VBE. Each task is modelled as a use case (graphically represented by the oval shapes within the VBE boundary). The ArchVBE supports two tasks: Access (i.e., the internal access to the data collection) and Consultation (i.e., the external consultation of the data collection). Each task is associated with one or more actors. Each association is modelled as a line connecting one task to one actor and represents a dependency between tasks and actors (either the actor uses the task or serves to some purpose in the task). The
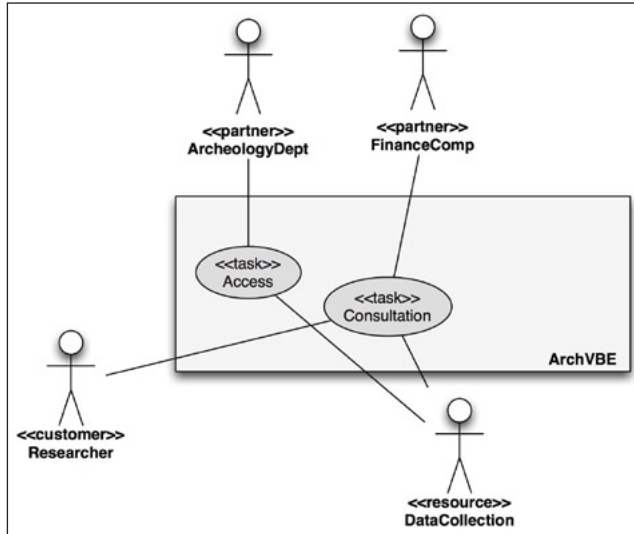
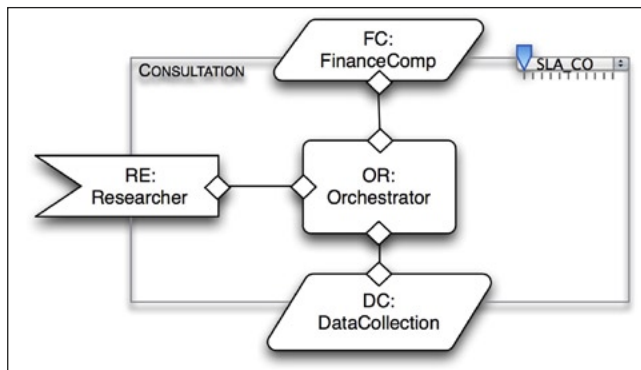Fig. 1 – Use case diagram of a VBE for archaeological projects.

Fig. 2 – Module defining the interfaces of Consultation.

task Access is associated with ArchaeologyDept (who can access the data) and DataCollection (the data). The task Consultation, for the external access to the data collection, is associated to actor Researcher (the customer of the consultation service), FinanceComp (the finance compartment that regulates the payment for the consultation), and DataCollection.

Following the notation from Bocchi *et al*. 2009, the use-case diagram in Fig. 1 allows us to derive a *module diagram* for each task. Each module
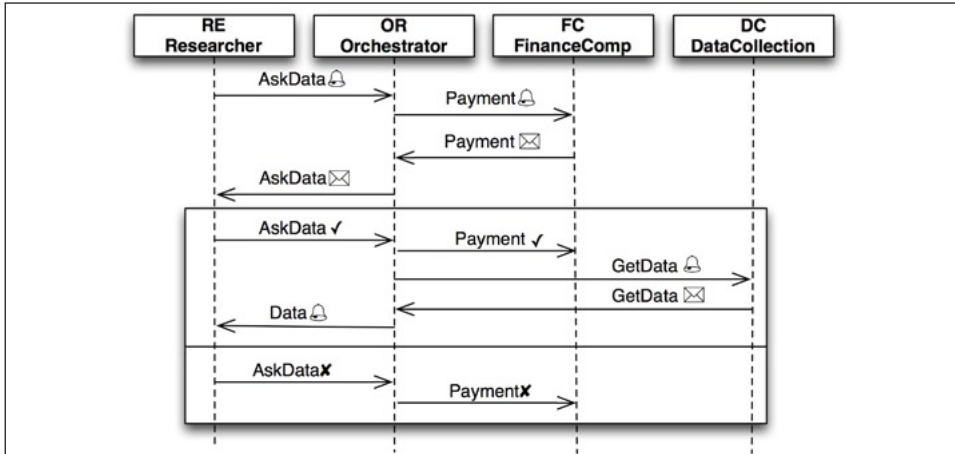
Fig. 3 – Sequence diagram of the interactions occurring in module Consultation.

focuses on one single task and helps to define the interfaces that should be involved in the implementation of that task. We focus here on the module for task Consultation, illustrated in Fig. 2.

The module in Fig. 2 describes a service launched by an external party RE, specified as Researcher. The aim of the indirection between the interfaces (e.g., RE) and their specifications (e.g., Researcher) is to enable the reuse of the same specification for different interfaces; this is useful when two interfaces are supposed to have the same behaviour, which however is not the case in this scenario. RE communicates with OR, which is a central component coordinating the interactions with the other interfaces FC and DC.

The interactions among the parties can be informally modelled by the UML sequence diagram (OMG 2011) in Fig. 3. As in Fig. 2, OR has a central role in the sense that all interactions are from OR to another party or *vice versa*. Notice that in fact the researcher interacting with the application could be a human, in fact RE could be a web interface with several buttons that support a human to go trough the interactions described in Fig. 3.

In Fig. 3, the overall conversation is started by RE that sends a message to OR to ask for some archaeological data (attaching also some payment data, not represented here). The symbol ♤ denotes the initiation of a number of correlated messages with the same name. Next, OR: (1) sends a message Payment to FC to ask to process the payment, (2) receives a reply to interaction Payment (replies are denoted with symbol ⊠), and (3) sends a reply to interaction AskData (e.g., specifying whether the payment was successful). Next RE can either: (top of the rectangular box) send a confirmation mes-

sage AskData✓ which causes Orchestrator to confirm the payment with FC, fetch the data from DC and forward them to Researcher, or (bottom of the rectangular box) send a cancellation message AskData✖ which causes OR to cancel the payment with FC.

So far we have used an informal notation from Bocchi *et al*. 2009, but there are formal ways to specify the protocol in Fig. 3 which also enable to specify and validate properties of the protocol itself. We will discuss this in Section 4.

3.2 *Starting a new excavation project (VO)*

Studies such as Barker 1986, Collis 2001, Roskams 2001 show that the excavation process is complex and requires multi-discipline experts and communities to collaborate and share resources. In order to tackle such complexity, it is important to break the organisational aspects of the excavation process down into smaller parts. We want the following functionalities to be supported:

– exposing a friendly interface to customers who may want to commission an excavation
– finding a local archaeologist to produce an excavation plan
– implement the excavation plan (if it is accepted by the customer)
– recruit the site personnel
– outsource digging
– recruit other experts.

More precisely, as a case study, we consider the following scenario:

A company wants to build a new store on a plot of land in the Midlands. In the process of sorting out the planning permission, it turns out that the plot of land contains archaeological remains. Before the work can go ahead, an excavation must be undertaken. The manager of the company asks the VBE ArchVBE described in Section 3.1 to organise an excavation in that specific site, bearing in mind that the following is needed (1) a project manager, (2) a recruiting agent, (3) trained staff for excavating and recording, (4) staff, tools and machineries for digging, (5) experts such as geologists, osteologists, material scientists, etc.

A VO is modelled as a particular use case to be added to the model in Fig. 1. Recall that VOs can be created and deleted through the lifespan of a VBE. Therefore, a VBE model that includes VOs describes the state of that VBE in a *precise moment in time*. We will call such model a *business configuration*, following Bocchi *et al*. 2009. The model for a business configuration can be obtained from the models of a VBE model by adding one or more VOs. For example, Fig. 2 illustrates the business configuration called Excavation obtained extending ArchBE with the VO ExcavateShop, represented as an
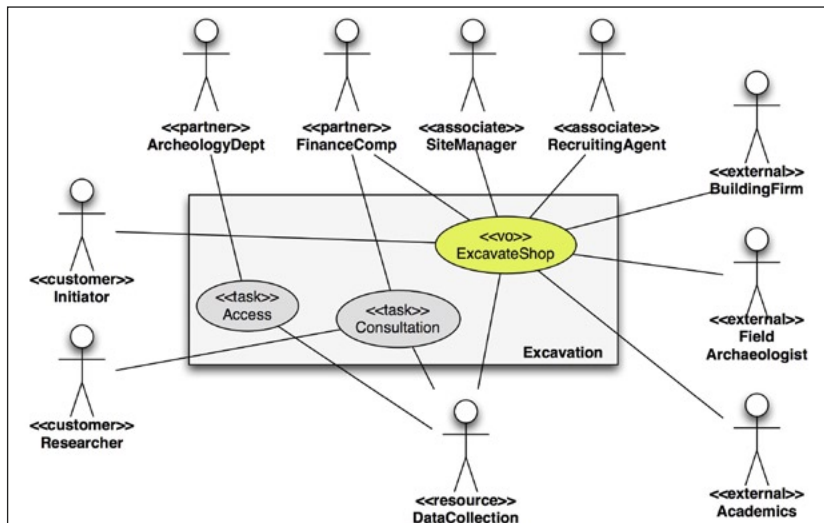
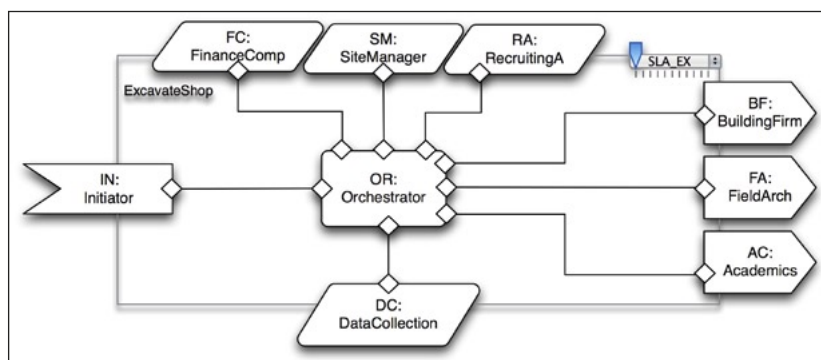Fig. 4 – Use case diagram of a VBE extended with VO ExcavateShop.

Fig. 5 – Module showing the interfaces of ExcavateShop.

oval. When introducing a VO, we may need additional actors. A VO can be associated to the same type of actors of a VBE task; furthermore a VO can be associated to one or more *associate* actors. An associate is an actor involved in the activity of a VO, therefore engaged in with the VBE until the goal of that VO will be achieved.

The VO ExcavateShop is associated with some of the actors of Ar-chVBE, namely FinanceComp (to handle the financial aspects of the project)
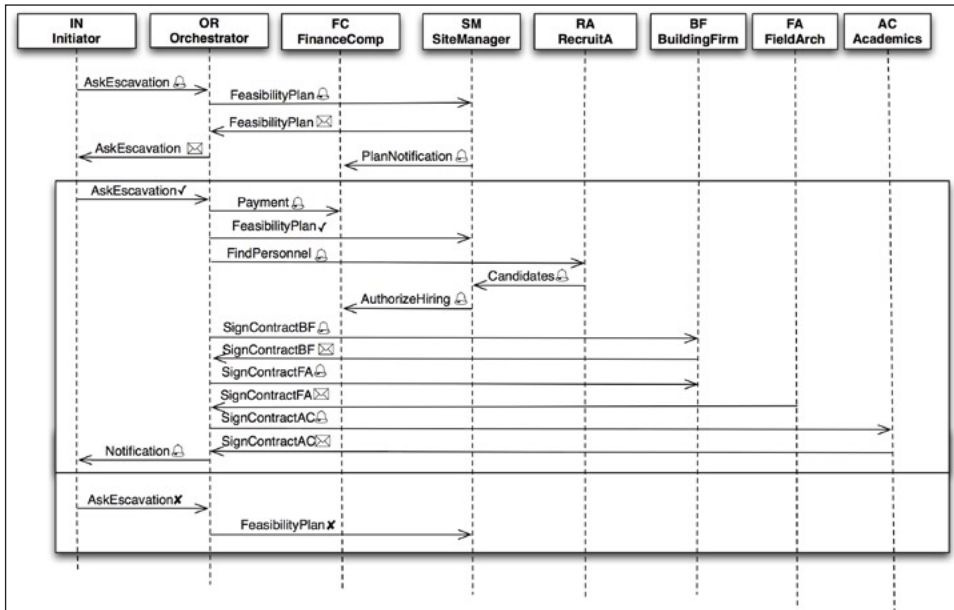
Fig. 6 – Sequence diagram of a fragment of the interactions occurring in module ExcavateShop.

and DataCollection (where the findings will be catalogued). Some additional actors are involved:

– a customer, called Initiator (i.e., the business man) who commissioned the excavation;

– two associates, called SiteManager, who supervises the activities of the excavation site, and RecruitingAgent, who serves as a broker for discovering suitable personnel;

– FieldArchaeologists, RecruitmentAgent, and Building Firm which are external members of the VO ExcavateShop providing temporary services for the recruitment of staff, experts and hiring machines at that particular region of the excavation.

Similarly to how we did in Section 2, we can derive a module for the VO ExcavateShop (Fig. 5) from the use case diagram in Fig. 4. The module provides a service with interface IN specified as Initiator. FC and SM are interfaces for the partners or associates that supervise the activity of the module. DC is the interface to the database of archaeological observables. BF, FA, and AC are services to be procured externally (i.e., outsourced).

Fig. 6 models the interactions performed within the virtual organization ExcavateShop when setting up the virtual organization (we omit interface

DC because it is not involved in this first phase). In Fig. 6, first IN makes a request AskEscavation⌂ for an excavation, which is processed by OR. Next, SM is requested to produce a feasibility plan which is returned to OR and then forwarded to IN via the interaction AskEscavation⌧. IN can either accept or refuse the plan (via AskEscavation✓ and AskEscavation✗, respectively). If AskEscavation✓ occurs, then a payment is put forward to FC, SM is acknowledged and RA is requested for a list of suitable candidates to hire (as field archaeologists, building firm, and academics). RA sends a list of suitable candidates to SM with interaction Candidates⌂. SM selects the candidates (possibly upon interview) and sends OR an authorization for hiring the selected personnel. OR then proceeds with the hiring/contracting and sends a notification to IN. If AskEscavation✗ occurs then no payment is issued and the feasibility plan is cancelled.

4. Model evaluation

The models presented in Section 3 encourage a systematic (and reusable) description of the activities involved in internal and external data accesses and excavations. The aim of the models is not to directly prescribe how human users should perform their activities. Those models are instead targeted at architects and software developers. The former uses the models to refine their design; the latter uses them to build applications to support human users during the whole process. The approach in Bocchi *et al*. 2009 offers two further advantages. The first one is that it exploits the abstractions of service-oriented paradigm, which simplifies the models by relying on middleware facilities such as automated service discovery. The second one is that it enables formal verification (Abreu *et al*. 2009) of correctness properties such as deadlock freedom. We will give a hint of the first aspect in Section 4.1 and of the second aspect in Section 4.2. Further considerations from the archaeological point of view will be provided in Section 4.3.

4.1 *Supporting Service Procurement*

The framework we use enables one to specify the information necessary at run-time to select appropriate services for the outsourced functionalities. This information describes what a module provides to the requestor (e.g., IN in Fig. 4), and what it requires when selecting an actual service among the available ones. The framework builds on the feature provided by the service-oriented middleware which uses this information to retrieve the appropriate services.

In our case study (e.g., when selecting, at run-time, actual services for interfaces BF, FA, EC in Fig. 4) the choice of the outsourced functionalities is delicate as it implies the signature of hiring contract. For this reason we

break down the discovery/selection in two parts: the first one is performed by RA who selects a list of candidates, and the second one is performed by SM who is responsible for selection and recruiting.

Given an outsourced functionality (e.g., interface FA in FieldArch, Fig. 4), we can model: (1) the functional properties (e.g., the interactions FA is able to undertake and their order/causality, which should fit the protocol described in Fig. 5), (2) the non-functional properties, expressed as Service Level Agreement (SLA) constraints.

As to (1), the module should require that any service that at run-time will be selected for fulfilling the role of FA will first be ready to receive an interaction of type SignContractFA⊖ and then will eventually send a reply with the signed contract SignContractFA⊠. The terms of the contract can be negotiated in terms of SLA (see point 2 below); the functional properties only involve the interaction patterns between the invoking party and the service. As to (2), we can define a set of constraints, SLA, for module ExcavateShop. Fig. 6 shows an example of SLA defining two constraints c_1 and c_2.

Constraint c_1 is on SLA variables FA.Degree (the degree required to the applicants for the field archaeologist position) and FA.Salary (the salary offered for the field archaeologist position). Constraint c_1 associates degrees of satisfactions, as numbers between 0 and 1 with 1 being the maximum satisfaction, to possible values of FA.Degree and FA.Salary: the best match (satisfaction 1) is an applicant with only a master degree, who will be paid 27.000£ per year, the second best match (satisfaction 0.5) is an applicant with a PhD, who will be paid 31.000£. All other matches should be discarded (satisfaction 0). This constraint prefers a PhD student rather than a postdoc (e.g., who may be overqualified) and sets the salary which we assume standard for the respective qualifications.

Constraint c_2 is on SLA variables that correspond to the parameter time of interactions SignContractFA⊖ sent by FA, FeasibilityPlan⊠ sent by SM, and AskEscavation⊠ sent by OR. The constraint is on the parameter time, i.e., the duration of (respectively) the contract with the field archaeologist, the duration of the excavation according to the feasibility plan prepared by the site manager, and the duration of the excavation in the plan forwarded by the orchestrator to the initiator. By c_2 the time in these interaction should be the same. We omit the definition of interaction parameters in this paper for simplicity. The interested reader may refer to BOCCHI *et al*. 2009 for further details.

The information (1) and (2) discussed above can be used:

– directly by RA to select suitable candidates from repositories of available personnel, and
– transparently by the framework to check that, upon contract signature, the choices of SM respect the given constraints.

4.2 *Formal verification*

Let us consider again module ExcavateShop. The behavioural description in Fig. 5 can be further refined to obtain a state-chart diagram for each interface. Fig. 7 shows the state-chart diagram of a fragment of the orchestrator OR. The transitions between states are labelled with the events triggering the transition and with the events that result as an effect of the transition; the syntax of the labels is of the form event[condition]/action where event is the interaction triggering the transition, condition is an optional guard that must be true for the transition to occur, and action is the interaction triggered by the transition. For instance, the transition between states OR_1 and OR_2 is triggered by AskEscavation⌂, has no guard and causes the event FeasibilityPlan⌂. The transition between OR_3 and OR_5 specifies a condition and can only occur if the parameter Reply of interaction FeasibilityPlan (i.e., FeasibilityPlan.Reply) is true, namely if the site manager was able to produce a valid plan.

Assume now that we want to consider, for the initiator, the state-chart diagram in Fig. 8. This is a naïve initiator that will always accept the plan proposal (AskEscavation✓). Using the model checking techniques in Abreu *et al.* 2009 one can detect that in some executions the business manager may get stuck without reaching the final state. In fact, if we compose the behaviour in Fig. 7 with the behaviour in Fig. 8, when FeasibilityPlan.Reply is False the orchestrator will go in the final state with no further action whereas the business manager will wait forever for a notification. Model checking can be used to detect similar situations, to validate a wide range of properties defined in terms of the interactions and their causalities, and to check that the functional requirements the module promises to the business manager will be actually fulfilled, assuming that the external services fulfil the properties specified by interfaces BF, FA, and AC.

4.3 *The model from the archaeologists' point of view*

The VO model, as it is introduced in this article, anticipates several steps in thinking through the organisation of an excavation. Whilst the model seems coarse at first, it can be extended and refined to suit scenarios that are likely to be repeated, for instance when a commercial archaeology company needs to organise several excavations at different sites dealing with a number of different governmental agencies, landowners and financiers. The firm can then reuse the model indefinably, changing individual agents and contractors as needed. A list of building firms, freelance field archaeologists, researchers and other involved parties can be held, which shortens recruitment processes and ensures the optimal composition of the team.

EXTERNAL POLICY

SLA VARIABLES

FA.DEGREE, FA.SALARY,
FA.**SignContractFA🔔.span**, SM.**FeasibilityPlan✉.span**, OR.**AskEscavation✉.span**

CONSTRAINTS

C_1: {FA.DEGREE, FA.SALARY}

$$Def(d,s)= \begin{cases} 1 \text{ if } d = \text{"MSc – archaeology" and } s = 27.000 \\ 0.5 \text{ if } d = \text{"PhD – archaeology" and } s = 31.000 \\ 0 \text{ otherwise} \end{cases}$$

C_2: {FA.**SignContractFA🔔.span**, SM.**FeasibilityPlan✉.span**, OR.**AskEscavation✉.span**}

$$Def(a,b,c)= \begin{cases} 1 \text{ if } a = b = c \\ 0 \text{ otherwise} \end{cases}$$
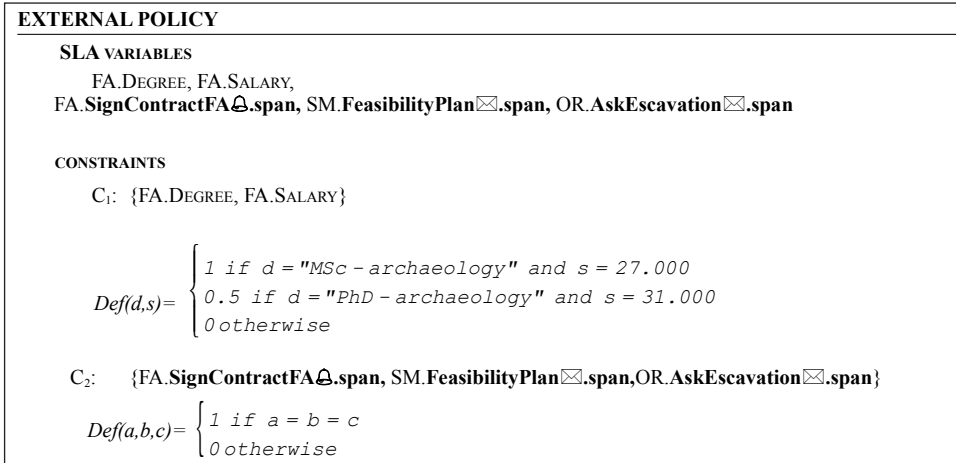
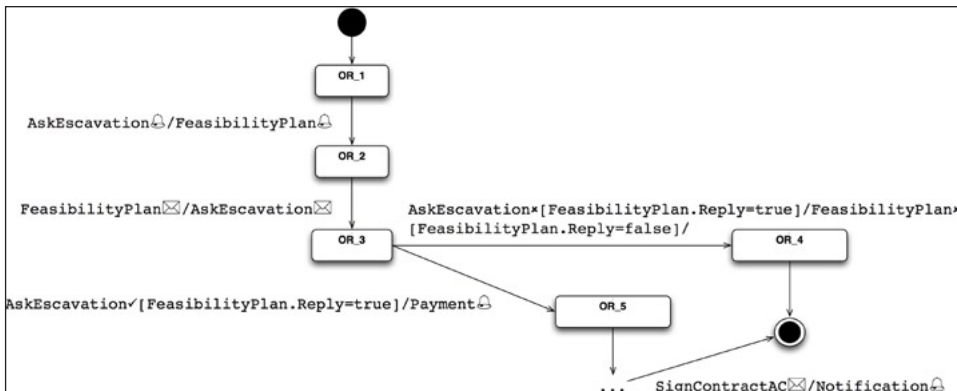Fig. 7 – A simple SLA constraint for module ExcavateShop.

Fig. 8 – (Fragment of) statechart diagram for Orchestrator.

The validity of the module extends even beyond the commercial sector, for instance in the case of university training excavations. In this case, the site manager is often a university teacher, and the team of field archaeologists are usually made up of both professionals and students to be trained. Other elements, the involvement of an archaeological institution such as the university or museum, building companies and specialist researcher remain the same. The financial aspect is increasingly dependent on external funding, through government and educational grants, but also through business-private partnerships or regional interest groups.
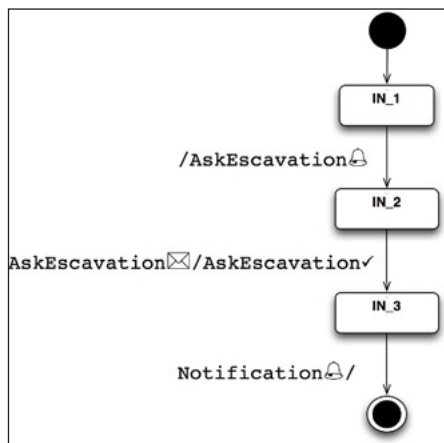
Fig. 9 – Problematic statechart diagram for Initiator.

Let us go back to our initial example of the excavation that led to the discovery of King Richard III's grave, and draw a correspondence between the roles involved and the actors of the VO ExcavateShop in Fig. 4. Richard Buckley (SiteManager) directed excavations on behalf of the ULAS, the University of Leicester's Archaeological Service (ArchaeologyDept). The excavation was initiated by the Richard III Society (Initiator), who found the sponsors, and the finances managed by ULAS (FinanceComp). Digging staff was primarily comprised of ULAS employees (FieldArchaeologists). The discovery of the skeletal remains needed immediate specialist attention by an osteo-archaeologist and a geneticist from the School of Archaeology and Ancient History of the University of Leicester, and subsequent analyses by a huge team of specialists (Academics). Not only was the site well-documented, but scientific data on all aspects of life and death of King Richard III were collected (DataCollection). The results were communicated to the public regularly; the latest press release on 4th February 2013 revealed the match of the buried body's DNA with living descendants of the last Plantagenet king[1].

The fact that this excavation was funded by more than one sponsor (i.e., not only by the Richard III Society but also, for example, the Leicester City Council) cannot be directly represented in our model. However, it is possible to represent other sponsors (than the initiator) with a straightforward extension to the model, e.g., by adding one associate actor Sponsor. This extension would

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[1] http://www2.le.ac.uk/offices/press/press-releases/2013/february/university-of-leicester-announces-discovery-of-king-richard-iii/

require additional interactions, e.g., between Sponsor and FinanceComp, but would still enable reuse of other parts of the model.

As this example has shown, the model applies even in such unusual cases, or if planning excavations follows a traditional system of using local expertise, trusted colleagues and established patterns of collaboration. The VO model thus does not undermine local structures, but helps to make them more explicit, whilst retaining flexibility for timely adjustments. Whilst profit-driven market economy might drive the use of a VO in some cases, it is not necessarily a path into neo-liberal organisation of excavations.

A further concern is the variability in the way in which excavations are organised on a national and trans-national level. Legal frameworks for heritage preservation differ enormously cross-culturally, even in Europe. As late as 1992, the Council of Europe suggested the Convention on the Protection of the Archaeological Heritage (Willems 2007), which has been slow in its implementation. Heritage preservation and archaeological research are regulated through different governmental bodies, and organised through public, semi-private and private institutions, primarily museums. Whilst interest in the past has increased in recent years, debate has arisen as to "who owns the past" and who has the right to investigate it, and by which means (e.g. Renfrew 2001; Gibbon 2005; Vitelli, Colwell-Chanthaphonh 2006). This is a pressing problem, especially in area where conflicts between indigenous and colonial interests were an issue historically, or where religious groups claim connections to archaeological remains. A VO model can be designed to address different cultural settings and allow stakeholders with different interests to participate in excavation processes.

5. Conclusions

The modelling exercise suggested a number of desirable extensions of the notation used in Bocchi *et al.* 2009 that would enable a more natural representation of the archaeological domain under consideration.

5.1 *Culture modelling*

As the considered framework supports worldwide VBEs and VOs, one should take into account that activities of the archaeologists may be constrained by cultural sensitivities. For example, the excavation of a site of archaeological interest may face cultural resistance because its location is sacred to the local community. The modelling framework for the VO should provide primitives that represent the culture associated to a site, in order to help archaeologists to consider this aspect. It is important to include the notion of culture in the modelling activity as cultures can affect the patterns of interactions among the participants that are described by the models.

Considering cultures at this early stage allows us to discard models that are difficult (or impossible) to implement. A viable solution is to annotate VOs with information on whether they are mono-cultural (i.e., VOs whose members are from the same culture) or multi-cultural.

5.2 *Human involvement*

The role of human cannot be overlooked in any organisation, virtual or not. The majority of tasks in archaeology are human dependant, such as site survey and onsite data recording, which require direct human participation. It is important for archaeologist to be able to model the direct human involvement in the VO. This includes tricky aspects such as managing sample transport across international boundaries, reaching agreements with local heritage managers and museum directors, having sub-contractors arrive on time to do specific tasks, maintaining and sharing databases, and organising analytical results from laboratories. Logistical organisation can be difficult, and can negatively impact a project. Division of labour amongst co-directors and international collaborators is an area where VOs might be more useful. This aspect of modelling is an ongoing research subject in service oriented modelling and other modelling methodologies. BPEL4People (OASIS 2007) is one of such proposals. This is a very complex part of modelling and it is beyond the scope of this paper to address it in detail. Since we only model at a high abstract level, however, it is possible to propose primitives that would represent direct human involvement. The modelling primitives proposed by BOCCHI *et al*. 2009 are the same for interfaces to human users and interfaces to automated components. This issue is not specific to archaeology: addressing it could improve the framework and make it more representative.

5.3 *Final comments*

Archaeological excavations are complex activities, fostering the collaboration of many different institutions, organizations and individuals. The seamless organization of an excavation may benefit from employing a Virtual Model for archaeological project development. It can streamline the process by initiating a VBE at the very beginning of project development and then working from within that VBE, avoid setbacks by providing some of the necessary primitives for things that might be forgotten (e.g. concerns of local stakeholders), make the process more efficient by creating spaces for participants to interact and plan their contributions (VOs), whilst keeping the process flexible (e.g. by providing a mechanism for updating heritage regulations, etc.). Defining a model of such activities may help to anticipate the appropriate steps necessary, avoiding problems and delays. Importantly, the model can be reused and adjusted for further projects. We have illustrated

that the model can be applied to different scenarios. Furthermore, our analysis shows that the standard notions of virtual organizations need to be extended in order to cope with specific aspects of archaeological excavations.

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ABSTRACT

Archaeological excavations are complex activities, fostering the collaboration of a number of different institutions, organizations and individuals. The seamless organization of an excavation may benefit from the use of a virtual model, which can be adjusted to the specific needs of the project. Defining a model of such activities may help to anticipate the appropriate steps necessary, in order to avoid problems and delays and, more importantly, can be reused and adjusted for further projects. In this paper we attempt to promote the use of virtual breeding environments and virtual organizations as a modelling framework for the managerial aspects of archaeological excavations and we illustrate the flexibility of the framework by applying it to different scenarios. Our analysis also shows that the standard notion of virtual organizations needs to be extended in order to cope with specific aspects of archaeological excavations.