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Preserving Information from Real Objects to Digital Shapes

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Abstract

Nowadays, the success of the scientific enterprise largely depends on the ability of sharing resources among the scientific community. This problem is particularly relevant in the field of Computer Graphics and Vision. During the last years specific domains ontologies are emerging in support of different contexts, aiming at facilitating automated resource-sharing among information systems in specific fields. A fast evolution of Computer Graphics and Vision is now conditioned by how research teams will be able to intercommunicate. The shared resources should preserve as much meaningful information as possible, in order to allow and improve collaborative research and complete understanding of complex tasks. A critical phase in Computer Graphics and Vision is the Acquisition Phase, which includes different conditions and properties related to the object to be scanned, to the surrounding environment or even to the knowledge of the scanning experts. The novelty of our work is the tentative to integrate Knowledge Management approaches to Computer Graphics and Vision and, in particular, we aim at preserving information when passing from the real world (Real Objects) to the digital one (Digital Shapes). This is a fundamental step for moving knowledge from humans to machines.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Shape Processing I.4.1 [Image Processing and Computer Vision]: Scanning, Shape Acquisition, Digital Shapes I.2.4 [Artificial Intelligence]: Semantic Web approaches, Ontologies, Knowledge Management

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1. Introduction

The success of the scientific enterprise largely depends on the ability of sharing different kind of informative resources among the scientific community. As pointed out by Hendler [Hen03] researchers may need to find and explore results at different levels of granularity, from other perspectives in a given field or from a complete different scientific field. This problem is particularly relevant in the field of Computer Graphics and Vision, which is based on a large spectrum of fundamental fields. Recently, the area has reached a state where each individual fundamental domain is well understood and exploited. A fast evolution of it is now conditioned by how research teams will be able to intercommunicate, in particular concerning the sharing of the basic kind of resources, i.e. the digital shapes. This resources should preserve as much meaningful information as possible, in order to allow and improve collaborative research and complete understanding of complex tasks.

But where is this meaningful information? Some of it is intrinsic of the shape (e.g. appearance, topological structure and geometry) and so it is naturally preserved in the digital world, some other is in the context (e.g. environmental conditions, location, ownership) and so is pertinent only to the real world in which the shared object was originally embedded. This kind of information is usually not associated to the digital model. A critical phase is the *Acquisition Phase*, in which the contextual knowledge includes different conditions and properties related to the object to be scanned, to the surrounding environment or even to the knowledge of the scanning experts. Most of this information must be preserved and passed to the other steps of often complex modelling pipelines, in order to improve the quality of the results and to open to new research approaches.

The novelty of our work is to integrate Knowledge Management approaches to Computer Graphics and Vision and, in particular, we aim at preserving information when passing from the real world (real objects) to the digital one (digital shapes). This is a fundamental step for moving knowledge from the human experts to the machines. We foresee a research generation in which Digital Shape Knowledge

is explicitly represented and, therefore, can be retrieved, processed, shared, and exploited to construct new knowledge.
In this paper we analyze the problem of linking Real and Digital, trying to preserve significant information during digitalization, with the specific intent of creating semantically enriched digital replica of real 3D objects. For this reason, we faced the problem of formalizing the Acquisition Process in a domain specific ontology, called Shape Acquisition and Processing Ontology (SAP).

The remainder of this paper is organized as follows: Section 2 presents some related work, Section 3 points out the requirements/observations when passing from the Real World to the Digital one. Section 4 depicts the informative power of digital shapes when correctly embedded in a specific context, and Section 5 presents our proposed ontology for Shape Acquisition and Processing, focusing the attention on the acquisition session. Finally, in Section 6 some concluding remarks are drawn.

2. Related work

In the last decade, the community working around multimedia has been more and more interested in the use of Knowledge Technology and Semantic Web approaches. Such interest is demonstrated at different levels by the adoption of ontologies and (ontology-driven) metadata.
The concept of metadata is adopted by the Multimedia Picture Expert Group (MPEG) within the specification MPEG-7 [mpe04] and MPEG-21 [mpe02]. In particular in the MPEG-7 metadata is used to provide standardized audiovisual descriptions for retrieval, categorization and filtering purposes, whereas in the MPEG-21 metadata is used to build a framework enabling the transparent and augmented use of multimedia resources across a wide range of networks and devices. In MPEG-7 and MPEG-21 metadata is solely expressed in XML, and not according to the whole ontology spectrum.

Some attempts to define ontology-driven metadata and adopt a deeper ontology spectrum has been carried out by Hunter [Hun03, Hun01]. He defines a core ontology to get semantic interoperability of multimedia and proposes two ontologies inspired to MPEG-7 and MPEG-21. Moreover, ontologies to describe the concepts pertaining shape have been developed also for a wide set of applications, in particular in the field of the Computer Aided Design (CAD) and the product design. Brunetti and Grimm [BG05] propose to adopt an ontology in order to describe how the CAD features are constituted. This kind of knowledge is usually implicitly embedded in the application together with the operations that are applied to the features.

The captured knowledge can be accessed by CAD systems as well as by other applications. Ontologies and STEP standards are proposed by Posada et al. [PTWS05] to obtain the semantic simplification of CAD models in different engineering domains. Kopena and Regli [KR03] argue the needs for design repositories, which take advantage from the Knowledge Representation techniques to overcome the problem of managing the complex information related to product design. However, all these works do not directly address the problem of preserving the contextual information related to shape, in particular related to the acquisition phase. Therefore the logistic and environmental conditions of the acquisition, and the tricks used to perform it are mostly ignored, and thus the related information is lost.

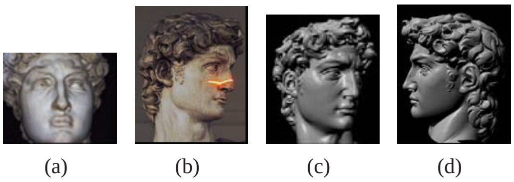


Figure 1: *The Michelangelo's David. (a)-(b) two pictures of the real statue. (c)-(d) two different views of the triangulated digital models (Images thanks to the Michelangelo Project - Stanford University www.stanford.edu)*

Finally, an ontological theory of physical objects is proposed by Borgo et al. [BGM97]. A framework for developing the basis of a general ontology of space, matter and physical object is proposed. An axiomatization to restrict the possible interpretations is also presented, according to some hypotheses such as: (i) space occupied by an object is different from the object itself, (ii) objects are made of matter but the matter is different from the object and (iii) some objects are immaterial. Their assumptions in our work could be considered to characterize the real objects. However, our work aims to stress the need of maintaining the information in the whole Shape Acquisition process, and so the main aim is to get a bridge between the real objects and their digitalized models. In this sense, the ontological theory described in [BGM97] could provide the basis to keep the consistencies among a real object and its representation after the real object is modified or corrupted.

Beside the aforementioned works, the research in the direction of systematically defining and adopting ontologies in multimedia is currently open, as demonstrated by the outgoing initiatives (The Multimedia Ontology meeting during EWIMT2005 [Mul]) and projects (AIM@SHAPE [AIM], aceMedia [Ace06]) which have been emerging in the last three years.

3. From Real to Digital

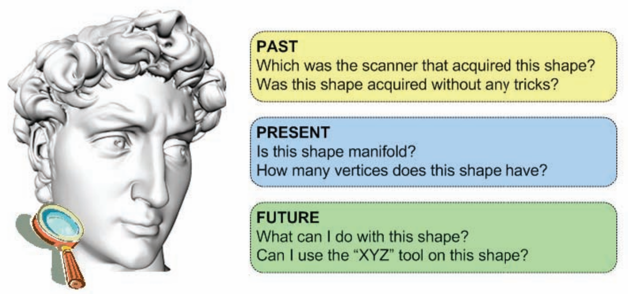
Formally representing objects through models is fundamental in any application field. The term model usually means a mathematical construct which describes objects or phenomena. The modeling step is done by defining the entities and rules which formally describe the object and its behavior, thus defining a symbolic structure which can be used and queried as if it were the object itself under certain conditions [FS98].

A lot of information about an object is conveyed through the use of models of the object itself, since much of our knowledge about the physical world comes to us in the form of shape information. On the one hand, architects, engineers, product designers have always used physical models and graphical representations for visualizing their hypotheses and to show their projects. On the other hand, a model can represent a real object, and can replicate its intrinsic information value. Examples are relief maps or, in cultural heritage applications, replicas of famous statues, (see Fig. 1).

The use of computers has given further emphasis to the informative purposes of Shape Modeling. At the beginning, this effort gave rise to research in Geometric Modeling, which sought to define the abstract properties describing the geometry of an object (geometric model) and the tools to handle the related symbolic structure. Terminology and definitions for the foundations of Geometric Modeling were first introduced in Requicha's seminal 1980 article [Req80], whose basic notions have shaped the whole field to this day.

Following his paradigm, considerable research activity has been developed in the two most well known representation schemes: CSG (Constructive Solid Geometry) and BRep (Boundary Representation), which have deeply influenced current commercial geometric modeling systems [M̈88]. However, the above representation schemes rely only on geometrical information which is not enough to fully characterize a shape. Additional information should be modeled and associated to digital models and some of this information must be taken from the real world. It is possible to consider an object evolving in time, and to note that several events can occur during its lifecycle. For example, when the object is a real object, it may become a part of another object in a construction process, or some parts of it may be substituted, or may get accidentally broken. When the object is in the digital world, for design purposes it may evolve according to the designer's intent, or may be reused in different contexts; for rendering purposes it can be simplified or optimized for specific hardware; for quality enhancing some tools may be used to smooth a noisy area, to fix unwanted holes, to localize and preserve the edges sharpness, and so on.

In this work we focus on the evolution of the object in its most critical phase: when it passes from the real world to the digital world. In other terms, in the process of its acquisition. The most important question that has to be posed is: what information has been lost in this passage? Which immediately drives to the question: how the acquired geometric model should be augmented to hold the information value that it had?



PAST
Which was the scanner that acquired this shape?
Was this shape acquired without any tricks?

PRESENT
Is this shape manifold?
How many vertices does this shape have?

FUTURE
What can I do with this shape?
Can I use the "XYZ" tool on this shape?

Figure 2: *An expressive characterization of a shape is made up by the information related to its history, the information intrinsically held by the shape itself and the information related to its capabilities*

Two interrelated observations can ease in answering to these questions. The first observation is that the information held by digital shapes cannot be merely geometric: the precise description of the boundary of an object is not all that characterizes it. The human perception goes beyond, as some structural information or even some high-level semantic information are immediately perceived by the humans approaching the object. The second observation is that when we observe a real object, it is in a specific place and it exists in a specific instant. In the real world the objects are not independent from the context (e.g. space, time, ownership) in which they are embedded.

Therefore, as the representation level should adhere at its best to the reality it describes, also the digital objects must take into account other levels than mere geometric information. We think that augmented information is a key issue in the field of Shape Modeling. In the AIM@SHAPE Network of Excellence [AIM] the above observations converge in one simple statement: digital shapes have to be coupled with both intrinsic and contextual semantic information. On the one hand, elaborated techniques are under development to produce and process not only geometric, but also structural and semantic data. On the other hand, domain specific ontologies are in their construction phase, and their aim is to capture contextual information of shapes (Virtual Humans [GTV*05], Industrial Design [UDC*05] which are used to deal with resources according to context-dependent views).

Thus, coming back to the question "How the acquired geometric model should be augmented to hold the information value that the real object had?", we thought that the key issue was to adequately formalize the contextual information related to the object and, specifically, to its acquisition phase. Then, this information should be kept together with the digital object as an added value. This formalization is achieved through the Shape Acquisition and Processing ontology, which will be further described in Section 5.

4. Scenario, Domain, Applications

In this section we present an exemplificative scenario to illustrate a possible application where the adoption of our ontology can demonstrate its usefulness. For clarity of the explanation, we will consider a scenario (the acquisition of a statue) which will lead to choices concerning the specific kind of digital resources (3D shapes) and the possible applications that could be addressed (real- or digital-based).

Suppose to have a 3D digital model of the Michelangelo's David whose physical counterpart is placed at the Uffizi Museum. Via inspection of the digital shape, we can discover that the quality of the head junction is not sufficient to study the way in which Michelangelo has created the David (e.g. which tools has used and how). In the case in which we can use the digital shape without any additional information, we can decide to re-plan an acquisition, relying only on the expertise of the acquiring researcher. Instead, if we can look at and evaluate appropriate additional information associated to the digital shape, we can reason on how to improve the quality of the planned acquisition (e.g. lighting conditions, logistic conditions, error estimation and so on). We could also understand that, with a given scanning device, the quality cannot be further improved and we should plan a new acquisition with another, more powerful, acquisition device. Thus, appropriated information can catch the expertise and the knowledge in a particular research field (in this case, Computer Vision) and can maintain it for reusing, sharing in other research fields (such as Computer Graphics and Geometric Modeling).

Note that, when passing from real objects to digital shapes, two interrelated macro-classes of applications can be identified:

1. One class is still related to the real world, such as acquisition planning and documentation. An acquisition expert looks at a real object (e.g. the statue) and plans an acquisition, choosing an acquisition system, defining particular lighting conditions and evaluating the existing logistic constraints. For example, in case of an historical statue, maybe, it could be not possible to move it for scanning it elsewhere and some future occlusions may appear. The acquisition process must be reported in details for documenting a research activity.
2. The other class acts only on the digital world, and it includes applications such as shape remeshing, shape enhancing, analysis and structuring. Once a digital shape is obtained (e.g. a digital replica of a statue), it can be analyzed in order to extract characteristic features or can be modified in order to enhance the quality of the model for visualization purposes.

The quality of the applications in the latter macro-class (2) can be improved if information related to the real world is kept together with digital shapes. For example, in documenting the acquisition procedure, information related to a real object can be attached to the obtained digital shape and maintained as a piece of its history: this information will be lost otherwise.

5. An Ontology for Shape Acquisition and Processing

Due to the intrinsic complexity of shapes, an ontology is necessary in order to reach a sufficient level of expressiveness. The ontology entities should provide a thorough characterization of shapes (Fig.2) by storing: (i) the information related to its history, such as the acquisition devices and techniques for creating it or the tools for transforming it (its past, e.g. for documentation), (ii) the information intrinsically held by the shape itself (its present) and (iii) the information related to its capabilities and potential uses, such as the possible steps that can be performed or the tools that can be used (its future, e.g., for acquisition/process planning).

Our desired ontology should be able also to represent different levels of sophistication describing a shape as a simple resource (e.g. for cataloging) and characterizing it according to its geometry (e.g. for rendering), to its structure (e.g. for matching and similarity), and to what it represents (e.g. for recognition or classification). Fig. 3 gives an example of a digital shape and its intrinsic characteristics: it can be seen as simple resource (e.g. name and URL), or can be considered by its geometric characteristics (e.g. a set of triangles and normals). It has a structure (e.g. the skeleton of a teapot) or it can be seen a teapot composed by a handle, a spout, a body and a tip. It is important also to take into account the different contexts where the shape can be used since the specific application determines relevant characteristics. For example, if the main purpose is to build a teapot, the identification of parts by which a teapot is composed is fundamental, while if the purpose is to let a robot grasp it, the localization of the handle is the only necessary task.

The existing branches of research in the field of Computer Graphics and Vision are interested in one or more of the above mentioned characterizations, but also on the conditions and the tools to pass from one characterization to another. Finally, it is important to note that shapes play a central role in Computer Graphics and Vision, but they do not represent the only kind of resource that must be characterized in the common framework. Every day, scientists work with shapes, tools and publications.

It is important to devise the role of these resources in different conceptualizations, making relationships among them explicit. For example, a scientist may want to evaluate her latest implementation of a method. In this case, it is interesting to figure out which are the tools providing other implementations of the same method, the publications related to the above tools and methods, or the shapes used as tests for the other implementations (e.g. for testing/benchmarking activities).

The domain of our Shape Acquisition and Processing (SAP) ontology is defined as the development, usage and

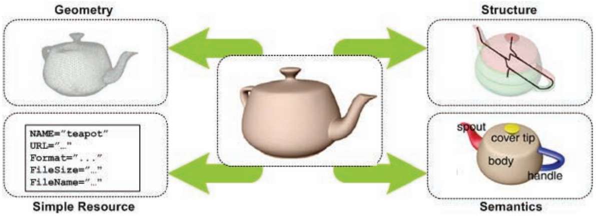


Figure 3: *A shape is described as a simple resource, or by its geometry, its structure, its semantics, depending on the application domain (part of the image courtesy of the AIM@SHAPE project)*

sharing of hardware tools, software tools and shape data by researchers and experts in the field of acquisition and processing of shapes. In the creation of the SAP ontology, the following macro-steps have been considered: *Shape Acquisition* (and Registration) - the phase in which sensors capture measurements from a real object; *Shape Processing* - the phase in which all acquired data are merged to construct a single shape and in which further computations may be performed (e.g. smoothing, simplification, enhancement, and so on).

Thus, the ontology target applications are related to acquisition planning, data validation, benchmarking, testing and data enhancement (e.g. automatic recovery).

The conceptualization arises from a process of elicitation which has taken place interviewing the experts within the NoE AIM@SHAPE [AIM] and from the assumption that the ontology is intended to be targeted to the scientific community. On the basis of the experts' needs, we have identified a set of formal competency questions, as for example: what are the Acquisition Systems able to scan a transparent real object? What tricks have to be performed in order to be able to scan a light absorbent real object? What Acquisition Systems are available at the DISI institute? In which environmental conditions the model was acquired?
Some of the identified competency questions are strictly related to the Acquisition phase, some others regard information related to real objects and/or digital shape and some other concern tools and algorithms managing digital shapes.

In the following subsection we will present in more details some concepts defined in SAP, presenting also relations and attributes. In particular we will present concepts aiming at modelling the knowledge related to the Acquisition Process. Its development has been made according to the OntoKnowledge approach [SSS04] and the SAP ontology has been expressed in OWL-DL [MvH*04]. Note that, in the following, what is written like THIS is actually an entity in the ontology we have developed using Protégé [MFNC01].

5.1. Modeling the Acquisition Process

The acquisition process basically deals with an acquisition session which takes place considering a particular real object and producing a digital shape on the basis of certain conditions. In SAP, the AcquisitionSession has been modeled as an entity and an overview of this entity is given in Fig. 4. The AcquisitionSession is related to an AcquisitionSystem (which is made up by one or more AcquisitionDevices - e.g. scanners) and to the AcquisitionConditions in which the acquisition is performed.

These AcquisitionConditions can be LogisticConditions (they include the presence of lights, if there exist any obstacle between the real object and the scanning device and so on) or EnviromentConditions (which include the information on is the type of environment - indoor, outdoor or underwater, the level of humidity or even the weather). Moreover, some attributes are directly related to the AcquisitionSession (e.g. the price for renting the technological devices), while others are related to the different entities in the framework (e.g. the person/institute responsible for a scanning system). An AcquisitionSession basically documents the acquisition of a RealObject and the production of a ShapeData (a digital shape), using a particular AcquisitionSystem. A RealObject has also been modeled as an entity, and the knowledge related to it and to its context is thus preserved: in the ontology are recorded the location of the object, the possibility to move it, whether or not it is transparent or light-absorbent, and so on. Note that the mentioned characteristics (e.g. transparency and being or not light-absorbing) have immediate impact on the Acquisition Planning. For instance, a Trick can be used when there is a problem of compatibility between the AcquisitionSystem and the RealObject to be scanned: a light absorbent object and a laser scanner might be incompatible, but if we need to perform the scanning, it is possible to avoid the problem by spreading powder over the object before scanning. Otherwise, it can also be possible to plan the acquisition with another (compatible) AcquisitionSystem. ShapeData (which identifies a digital shape) has been modeled as an entity with some specific properties, such as format, URL, description, source (i.e. the AcquisitionSession that has produced it) and owner (an Institution or a Person). A ShapeData can be based on another (or more than one) ShapeData, or a ShapeData can be used to generate a new one. The relation isDerivedFrom formalizes the knowledge related to the history of a given shape.

The ontology introduced so far, even if here only partially described, is already sufficient to describe the macro-step of the acquisition of a real object. Such a simple description provides the basics to embed in the digital shapes information that usually gets lost after acquisition. This information might result important for comparing shapes coming from different providers, for improving the assessment about their

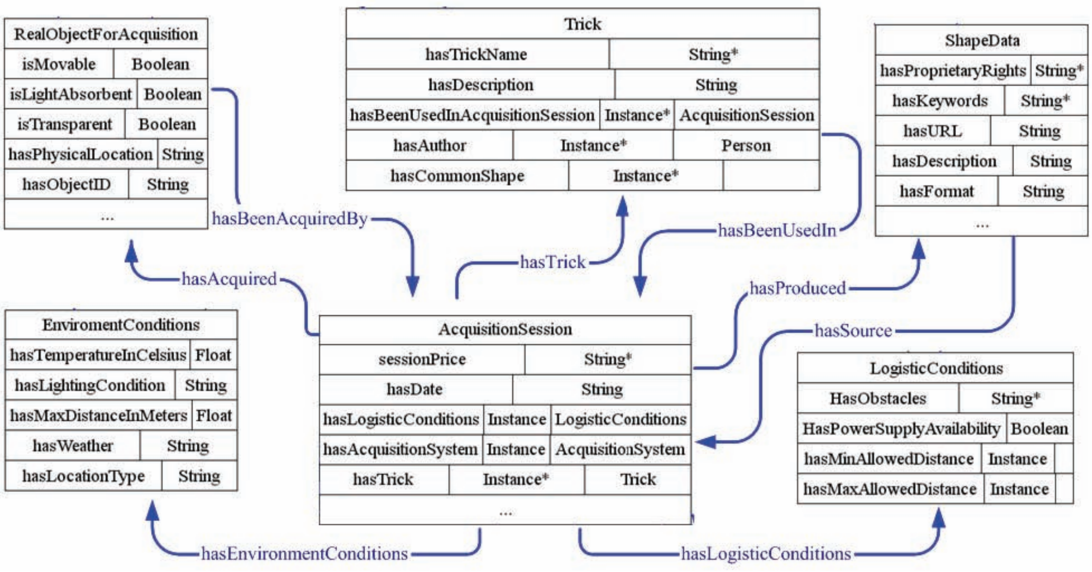


Figure 4: *A zoom on the* ACQUISITIONSESSION *entity in our ontology. The most significant relations are highlighted by arrows. Each rectangle represents an entity. The rows in each entity represent a slot which can be either an attribute or a relationship. For each attribute the type is specified, while for each relationship the range is indicated. Whenever a symbol '*' appears next to the name of an attribute or a relationship, the cardinality can be more than 1.*

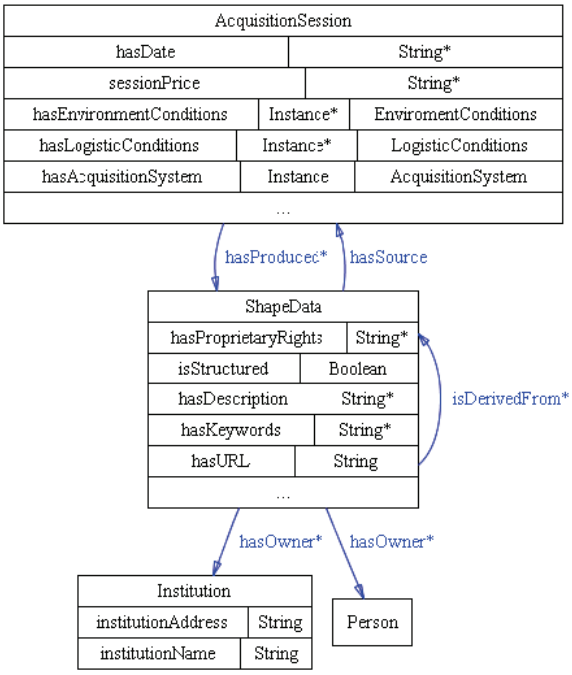


Figure 5: SHAPEDATA *entity and its relation with the* ACQUISITIONSESSION *entity.*

quality and for better understanding the results arising from further processing.

6. Concluding Remarks

The aim of this work was to create a bridge between real world and digital world, trying to preserve significant information during digitalization, with the specific intent of creating semantically enriched digital replica of real 3D objects. Everything was driven by the question: "What information has been lost when passing from Real to Digital?", that basically means to discover how the acquired geometric model can be augmented in order to hold real object information value.

We followed the path that leads to the integration of Knowledge Management and Computer Graphics and Vision outlining the need of a context-based reasoning on digital shapes. We have presented our ontology for Shape Acquisition and Processing (SAP), focusing the attention on the acquisition phase. With SAP, Real and Digital worlds are linked: we are able to preserve meaningful information from real objects to digital shapes. This information enhances the informative power of 3D digital models allowing a new way of reasoning in the digital world. With SAP, digital shape knowledge is explicitly represented and, therefore, can be retrieved, processed, shared, and exploited to construct new knowledge. Future issues will be the integration of the information related to the further processing and the analysis of the acquired/processed digital shapes.

Acknowledgments

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