ARPENTEUR 3.0: Recent developments in web based photogrammetry

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ARPENTEUR 3.0: RECENT DEVELOPMENTS IN WEB BASED PHOTOGRAMMETRY

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ABSTRACT:

Experiences and recent developments of a WEB application dedicated to digital photogrammetry are presented. The aim of the ARPENTEUR project (as Architectural PhotogrammEtry Network Tool for EdUcation and Research) is to propose a photogrammetric concept and software embedded in Web technology and Java programming language. Photogrammetry and 3D modeling tools are available on the Internet with a simple browser (http://www.arpenteur.net). Four years ago the first prototype of ARPENTEUR was based on the Java Development Kit (J.D.K. 1.1) at the time only available for some browsers. Nowadays, we are working with the J.D.K. 1.4 plug-in enriched by Java Advancing Imaging (J.A.I. 1.1) library. The local computer simply requires the installation of these plug-ins. Different photogrammetry projects have been presented since the Amsterdam ISPRS congress in 2000:

- stone by stone photogrammetric survey using architectural knowledge,
- I-MAGE process (Image processing and Measure Assisted by Geometrical primitive),
- 3D plotting and orthoimage generation,
- underwater photogrammetry and web integrated documentation system.

Photogrammetric solutions are available for the orientation of any kind of digital images (with fiducial marks, réseau, or non metric ones). Orientation results can also be imported from the PhotoModeler™ package in order to focus on the modeling modules available in ARPENTEUR without having to measure again the orientation points. In the version 3.0 of ARPENTEUR, XML "documents" as data and result files are built. XML is a markup language for documents containing structured information. XML technologies strongly separate presentation and content, and thus are an ideal means to present, understand, manipulate and transfer data between users and applications. We propose to discuss in the paper about photogrammetry and XML language, with a proposal of "model definition" as a first step towards a specification for structured documents in photogrammetry and their use on the web.

RESUME:

Les expériences et les développements d'une application internet dédiée à la photogrammétrie sont présentés dans cet article. Le but du projet ARPENTEUR est de proposer un concept et un logiciel de photogrammétrie développé en Java et fonctionnant sur le Web. L'accès aux outils de photogrammétrie et de modélisation en 3D est possible à l'aide d'un simple navigateur à l'adresse http://www.arpenteur.net. Il y a quatre ans, le premier prototype d'ARPENTEUR était basé sur la version 1.1 du J.D.K., à l'époque seulement disponible sur quelques navigateurs. Actuellement, nous travaillons avec la version 1.4 du J.D.K. enrichie par la bibliothèque J.A.I. 1.1. Ces plug-ins sont à installer sur l'ordinateur désirant se connecter à l'ARPENTEUR. Différents projets de photogrammétrie ont été présentés depuis le congrès de l'ISPRS à Amsterdam en 2000:

- une approche du relevé photogrammétrique pierre-à-pierre basée sur la connaissance architecturale de l'objet,
- une méthode de mesure (I-MAGE) basée sur la mesure de primitives géométriques associée à la corrélation d'images,
- un module de restitution en 3D et de génération d'orthophotos,
- un module de photogrammétrie subaquatique associée à un système de gestion des données des relevés archéologiques.

Différentes solutions photogrammétriques sont proposées pour l'orientation des images, quelque soit leur type (avec repères de fond de chambres, avec réseau ou non-métriques). On peut également importer dans l'ARPENTEUR les résultats des projets calculés avec le logiciel PhotoModeler™, afin d'utiliser les modules de modélisation sans refaire les orientations. Dans la version 3.0, le langage de traitement des documents XML est utilisé pour décrire les données et les résultats de la restitution. XML est un langage de marquage permettant de créer des documents avec une information structurée. Les technologies XML séparent clairement la présentation et le

contenu, et sont ainsi des moyens intéressants pour présenter, comprendre, manipuler et transférer des données entre les utilisateurs et les applications. Nous discutons dans cet article de l'apport du langage XML en photogrammétrie à partir d'une proposition de « définition du modèle » en vue d'une spécification de formatage des documents utilisés en photogrammétrie.

1. INTRODUCTION

This paper is aimed at showing the current developments of a web-based digital photogrammetric software called ARPENTEUR (ARchitectural PhotogrammEtry Network Tool for EdUcation and Research). Designed in 1998 by two French research teams (GAMSAU-CNRS and ENSAIS), this software has been developed in JAVA for a use on the Internet. The running of this package requires a simple browser, like Netscape Communicator or Internet Explorer. Thus it can be easily and freely used from anywhere, all over the world and with whatever operating system. Two servers, located in Marseilles and Strasbourg, France, are available currently to manage project data (www.arpenteur.net). The use as a local application (without web connection) is also possible. ARPENTEUR is mainly dedicated to architectural photogrammetry and close range terrestrial photogrammetry, but aerial images (limited to a few Mb) can be also handled. It accepts photos from a wide range of calibrated cameras (metric and non-metric camera, digital amateur camera).
Several references and information about the configuration are given on the arpenteur's web page.

The present paper is intended to present the work from the two past years, following the Computer Assisted Teaching contest (CATCON) organised by WG VI/2 in Amsterdam (2000), where ARPENTEUR has been awarded.

2. DEVELOPMENTS SINCE ISPRS 2000-AMSTERDAM

ARPENTEUR is above all a photogrammetric tool and proposes different solutions for the orientation and restitution of the models (Grussenmeyer & Drap, 2002). Several modelling modules dedicated to architecture or archaeology have been added. The outlines of the latest developments are given in this chapter.

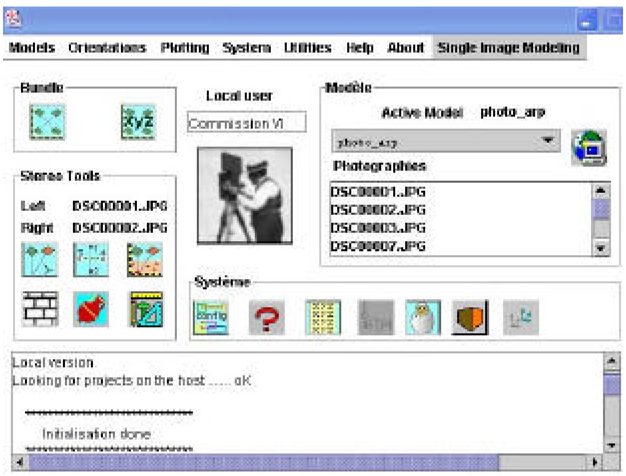

Figure 1. Main frame of Arpenteur 3.0

2.1 Image Processing

Measurements are done semi-automatically and area based-correlation is used to determine the required sub-pixel position in the digital image. Image processing techniques from Java Advanced Imaging API (J.A.I.) are used for manipulating and displaying images. New image editing functions have been proposed since 2000 (zoom in an additional view, interpolation, image editor, image enhancement, stereo window based on the anaglyph technique, different cursor index, etc.).

2.2 Restitution from couple of photographs

Points, lines, linestrings, curves and shapes can be measured in the restitution module, and directly compiled in the Bentley DGN format. Other well known export formats are VRML and POV-Ray. The data is also recorded in XML files (see §4).

2.3 I-MAGE module

For objects based on geometric primitives (as planes, cylinders, cone or sphere shapes), we can combine image correlation and the geometry of the object for the calculation of 3-D points.

This **I-MAGE** method (as **I**mage processing and **M**easure **A**ssisted by **GE**ometrical primitive) is based on four steps (figure 2), considering that a geometric primitive has been measured from a set of 3-D points visible on a couple of images.

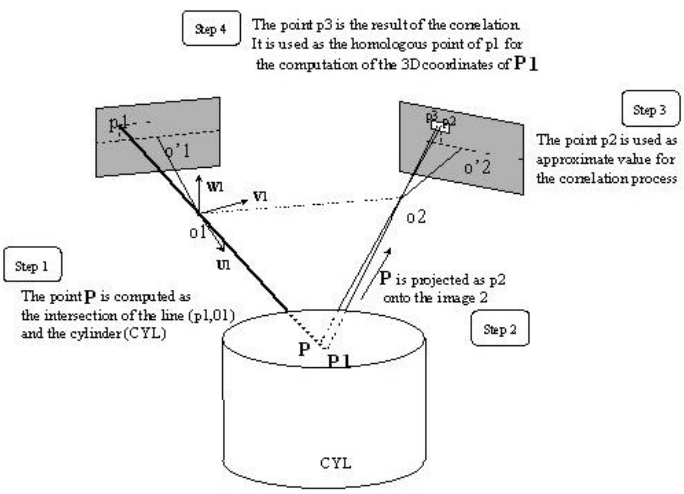

Figure 2. Four steps of the I_MAGE module.

For each computed primitive, the user can guide and follow the different steps of the measuring process (display the parameters of the primitive, compare the 3D coordinates of P and P1, compare the measured point (p1) and its homologous (p3) in the

image). The process allows accurate analysis of the object geometry.
VRML files with photorealistic textures are obtained from the combination of the restitution and IMAGE module when measuring plane shapes.

2.4 Stone-by-stone architectural photogrammetry

In (Drap et al., 2000), an application of a polyhedron representation of objects made of stone blocks has been presented. From a previous analysis of an edifice (usually conducted by an archaeologist), the characteristics and the chronology of a construction, as well as the properties of all measurable architectural entities can be defined. Stone blocks only measurable from their visible face (figure 3) are then computed with an approximate depth and the different blocks are ordered according to topologic and geometric rules.

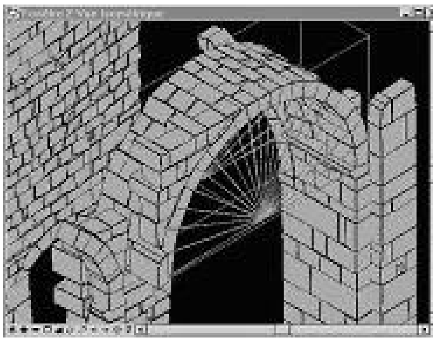

Figure 3. Example of architectural modelling.

2.5 Underwater photogrammetry system

The Arpenteur team has been involved in different projects of underwater archaeology (Drap et al., 2001). In the frame of the cooperation with L. Long, Cultural Heritage Curator at the DRASSM in Marseille, the Grand Ribaud Etruscan Wreck (discovered in 2000) has been surveyed with an exploration vessel Minibex of the COMEX (a French company). The digital camera used for the photogrammetric survey was mounted in a waterproof box and monitored from the submarine. The map of archeologic site has been plotted from this survey and a special module for the modelling of the amphorae has been developed in Arpenteur (figure 4). A paper explaining the XML documentation system of the Grand Ribaud Etruscan wreck has been presented at the ISPRS comm. V symposium in Corfu (Drap. et al., 2002).

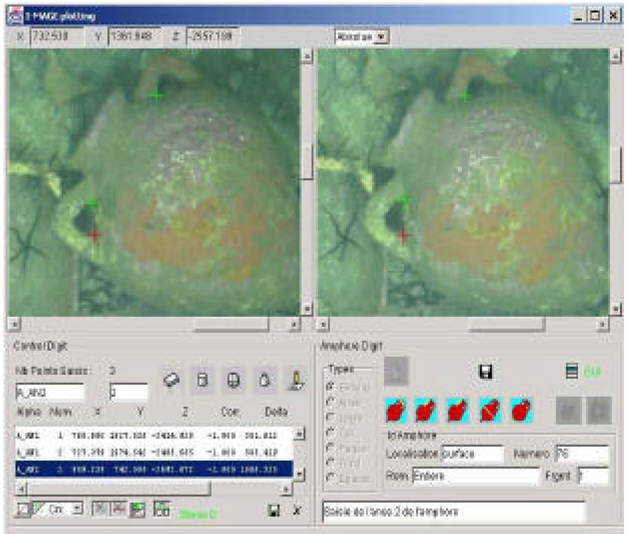

Figure 4. Modelling of amphorae in Arpenteur
Results are available at http://GrandRibaudF.gamsau.archi.fr

2.6 Single image restitution

A single image modelling method available as a special module in Arpenteur is proposed in Al Khalil and Grussenmeyer (2002). Single image techniques based on projective geometry aspects as vanishing points and homography are adopted (figure 5). The adoption of topologic modeling in a relational database management system is used for the management of data. Different examples of indoor and outdoor modeling of buildings have been tested.

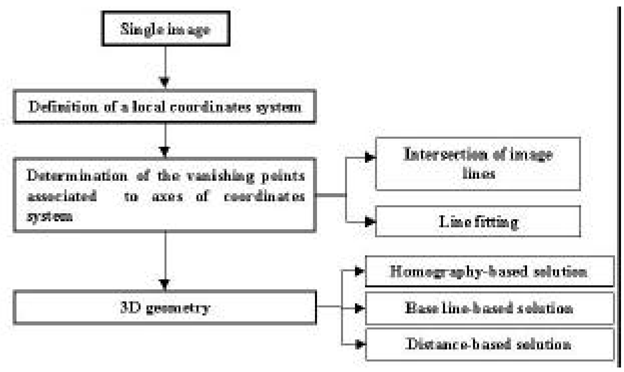

Figure 5. Single image modelling solutions

2.7 XML and interoperability

The XML specification defines a standard way to add markups to documents. In the version 3.0 of ARPENTEUR, XML “documents” as data, report and result files are built (Drap et al., 2002). XML is a markup language for documents containing structured information. This markup language is a mechanism to identify structures in a document. XML technologies strongly separate presentation and content, and thus are an ideal means to present, understand, manipulate and transfer data between users and applications.

As an example, markups of a control point file can simply defined by:

```xml
- <controlPointList>
    <point3D pt="Ptcalage 1 2.598 0.571 7.449" />
    <point3D pt="Ptcalage 3 3.795 0.397 6.793" />
    <point3D pt="Ptcalage 4 3.745 -1.019 6.020" />
    <point3D pt="Ptcalage 5 2.644 -1.094 6.583" />
```

In the camera file , more markups are required:

```xml
<camera>
  <description name="NikonCoolpix19dr8r" type="null" serial="null" date="Thu Mar 07 13:58:14 CET 2002" />
  <!-- Unit : mm -->
  <geometry focalLength="14.469" ppx="-0.170" ppy="0.006" />
  <!-- Unit : mm -->
  <fiducial shape="dot" number="4" system="coordinate" coordList="-5.999 4.495 5.999 4.495 5.999 -4.495 -5.999 -4.495" />
  <!-- Unit : pixel -->
  <digital width="2048" heigth="1536" />
  <!-- Unit : mm -->
  <distortion active="yes" type="radius" distance="1.0" values="0.0 9.2E-4 0.00736 0.02484 0.05888 0.115" />
  <decenteringDistortion active="yes" p1="6.0E-5" p2="3.0E-5" />
</camera>
```

A proposal of XML schema for photogrammetric models will be presented in paragraph 4 XML technologies offer many benefits, as for example ease of data transformation and the ability to readily integrate spatial and nonspatial data.
The exchange of data between different teams used to work with different software is a daily problem. The ability to exchange or share data is also known as the “interoperability” issue and is a concern of the Arpenteur project as a web based tool (Drap & Grussenmeyer, 2000). The use of the XML formalism is a rational choice to provide simple and efficient way to exchange data. As an example, PhotoModeler™ projects can be imported in ARPENTEUR. The Photo Table and the project text file are used to compute XML files. Photos are thus directly usable for further modelling and the orientations have not to be done again. Edition and visualization of XML files are very convenient.

3. CURRENT POSSIBILITIES AND LIMITS

An overview of advantages and limits of Web photogrammetry is given in this paragraph.

3.1 Advantages

- Install-free approach (only plug-ins to install)
- No limit of operating system
- Always the latest version is available on the server (no upgrade on the local computer)
- No limit of users (but it depends on the server capabilities)
- Access to the user project and data possible from any computer at any place and any time
- Advantages of Java (true object oriented language)
- Powerful classes of Java libraries (J.A.I., Java 3D)
- Data storage possible on the server or on the local computer (result files on the server only)
- Use in education and example projects available
- Use of XML (structured documents)

3.2 Limits

- Configuration of the computer required (a few minutes only), after download of the plug-ins (confusion of versions may happen)
- Irregular data flow on the Internet (fast Internet required)
- Image format usable (GIF recommended, JPG possible but memory consuming)
- Limitation for large images
- Image processing is time consuming (limits due to J.A.I.)
- No true stereo measurements
- Recent computer with 256 Mo RAM required (512 Mo RAM recommended)

3.3 Configuration of the computer

ARPENTEUR is not installed locally on a computer but the package is available as an applet by a simple web browser as Nestcape™ Navigator or Microsoft™ Explorer.

A web browser is usually able to handle a specific level of Java but this level depends on the version of the browser. Problems will occur if the Java classes installed on the ARPENTEUR servers have a different level in the browser. To avoid errors and to allow the use of any browser, the user must install some plug-ins provided by SUN™ :

- we are currently working with the J.D.K.1.4 [Arpenteur 3.0]. Consequently, this Java plug-in is required;
- the Java Advancing Imaging (J.A.I. 1.1) and Java 3D plug-ins are also required since classes from these packages have been in use;
- the CLASSPATH setting (in the configuration panel under Windows NT/2000, or in the autoexec.bat file under Win95/98) follows in order to indicate the folders containing the plug-ins and the libraries;
- the Java security level of the computer must be changed because the user has to grant the applet to read and write files on the client (local) disk, and this is usually not allowed for common applets. A “.java.policy” file is given and must be copied on the computer.
- we recommend also to activate the so-called Java Console to follow the different steps when running the software. Another file (called “controlpanel.bat”) is proposed for this activation.

Even if this configuration seems to be a heavy procedure, only a few minutes are required for the configuration. A detailed procedure is given on the project’s web page (www.arpenteur.net) as an assistance to the configuration. Of course the upgrade of the software package itself is directly done by the administrator on the server and the user always works with the latest version.

4. XML STRUCTURE OF DOCUMENTS

XML has been chosen to structure the photogrammetric orientation data and to represent the measured data collected during the restitution.

Considering the heterogeneous character of the data to manage in a photogrammetric survey, XML structuring is a solution to organize data in a single document. It is then possible to elaborate queries on the whole set of data (as we can do in traditional DBMS with SQL) and write simple and automatic reports in HTML or PDF. The document structure is described in a separate file, what allows the user to get only the relevant information. It seems that no official standard XML based representation of photogrammetric data has been proposed in our photogrammetric community.
To reach the goal of interoperability, we need a so-called Model for photogrammetric projects. To describe such a Model, we use XML and XML Schema languages. We are currently working on the formalization of a photogrammetric “Model” with the aim to propose a standardized way to describe photogrammetric data.
We are interested in contributions of research groups, software providers and other colleagues in order to propose a standard.

4.1 XML and XML Schema

Many technical specifications for the Web infrastructure have been developed by the W3C consortium (http://www.w3c.org) to promote interoperability.
Among these efforts, "the XML 1.0 Recommendation (published in February 1998) was the first step towards the next generation Web, allowing each community to design languages that suit their particular needs and integrate them harmoniously into a general infrastructure based on XML" (http://WWW.w3c.org/Consortium/) The XML specification (Extensible Markup Language, 2000) describes "a syntax created by subsetting an existing, widely used international text processing standard (Standard Generalized Markup Language, ISO 8879:1986(E) as amended and corrected) for use on the World Wide Web". For that, "XML documents are made of storage units called entities, which contain either parsed or unparsed data. Parsed data is made up of characters, some of which form character data, and some of which form markup. Markup encodes a description of the document's storage layout and logical structure. XML provides a mechanism to impose constraints on the storage layout and logical structure". The XML language defines the concept of well-formedness and validity: a well-formed document simply respects the XML way of structuring elements whereas valid documents respect some constraints on document structure. (Extensible Markup Language (XML), 2000).
The XML Schema specification (XML Schema Part 0, Part1, Part 2, 2001) is built atop the solid foundation provided by XML and provides a way to define in a separated document (written itself in XML) the structure of entities, their datatypes, the relationships between these entities and constraints as well. The so-called schema gives thus the conditions for a given document to be declared valid with respect to this schema.

4.2 Description of photogrammetric models

All projects and results in ARPENTEUR 3.0 can be expressed with XML as a basic storage. This version makes use of a DTD (Data Type Definition file) that defines the validity of photogrammetric projects written in XML. Contrary to XML Schema, a DTD does neither permit the definition of complex types nor provide the ability of performing uniqueness checking or referential integrity validation. That’s why the definition proposed here is presented through XML Schema. The schema and the resulting documents are human legible and reasonably clear (figure 6).
The 'model' element consists of seven subelements:

- model-description
- orientation-list
- photography-list
- point2D-lists
- point3D-lists
- controlPoint-list
- and three attributes, version, author and geoSystem.

Each subelements might contain other subelements, and so on until a subelement contains a data rather than any subelement. Elements that contain subelements or carry attributes are known as complex types, whereas elements that contain data are known as simple types. The types’ definition is an XML Schema that enables type checking during document parsing. It allows also the use of a query language (Xpath) to assert additional constraints, like uniqueness or referential integrity.

```
<xsd:element name="model">
   <xsd:complexType>
   <xsd:sequence>
              <xsd:element name="model-description"
   type="ModelDescriptionType"/>
              <xsd:element ref ="orientation-list"
                                  minOccurs="0" />
              <xsd:element ref ="photography-list"  />
              <xsd:element ref ="point2D-lists"      />
              <xsd:element ref="point3D-lists"       />
              <xsd:element name="controlPoint-list"
                 type="PointList"  minOccurs="0" />
              <xsd:element ref ="block-list"/>
   </xsd:sequence>
   <xsd:attribute name="version"  type="VersionType"
                                  use="required"/>
   <xsd:attribute name="author"  type="xsd:Name"
                                use="optional"/>
   <xsd:attribute name="geoSystem"
                           type="geoSystemType"
                           default="LSR"/>
  </xsd:complexType>
</xsd:element>
```

Figure 6. Excerpt of photogrammetric model definition

More details about our proposal of model subelements and other main elements are available at the following web page:

http://arpenteur.gamsau.archi.fr/ModelDefinition/index.html.

5. TEACHING EXPERIENCES

5.1 ARPENTEUR as a teaching tool

The use of ARPENTEUR has been included in practical applications for under-graduate students of the Department of Surveying at ENSAIS. Using ARPENTEUR permits them to get a better knowledge of basic photogrammetric techniques (e.g. stereoplotting, image correlation, architectural photogrammetry and architectural modeling) in an original and very attractive way. Output results can then be viewed as text and XML files, DGN, VRML files for a further processing on the Internet or CAD systems (e.g. MicroStation).

A step by step guideline for configuring and using the version 2 of the software has been prepared by Ferhat (2001), based on a stereopair of aerial images (figure 7).

Figure 7. 3D restitution of aerial images

Experiences in terrestrial photogrammetry have been made in Helsinki (Renfer & Daeffler, 2001) and by students from Thessaloniki during a training period in Strasbourg in the frame of a European mobility programme.

5.2 Interoperability with PhotoModeler

Several universities and offices are working with the commercial PhotoModeler package. At ENSAIS, this package is used for both aerial and terrestrial photogrammetry applications in the frame of an 'urban imagery' project (Neusch & Grussenmeyer, 2002). In the underwater photogrammetry projects (§2.5), PhotoModeler is used for the camera calibration and for the site restitution from large blocks of images.

The results from the photo table and project text file of PhotoModeler can be imported in ARPENTEUR and written automatically as XML files. All orientation results are then directly reusable for other modelling applications in our software. The following XML files are created after importation (control point file, camera file and model file). When programming such interfaces, difficulties in the interpretation of the reference coordinate system used in the PhotoModeler output files show that a standardisation of the photogrammetric model is really a need. XML seems to be the solution for a better interoperability.

6. CONCLUSION

An overview of the latest developments of the ARPENTEUR project has been given in this paper. Additional measuring methods based on semi-automatic primitive measurements have been included in the package. The main point is the generalization of the XML language for all documents handled by the software. We hope that the proposal of photogrammetric "model definition" based on the XML schema specification will interest the reader and be followed by discussions. Our proposal of specification is available on the project web page (www.arpenteur.net). ARPENTEUR is also a modern teaching tool since photogrammetry and modelling tools are embedded in the latest web technology techniques.

7. REFERENCES

References from Journals:

Drap, P., Grussenmeyer, P., 2000. A digital photogrammetric workstation on the web. *Journal of Photogrammetry and Remote Sensing* 55(1): 48-58.

References from Other Literature:

Al Khalil, O., Grussenmeyer, P., 2002. Single image and topology approaches for modeling buildings. *ISPRS Comm. V Symposium*, Corfu, Sept. 2-6, Greece.

Drap, P., Gaillard, G., Grussenmeyer, P., Hartmann-Virnich, A., 2000. A stone-by-stone photogrammetric survey using architectural knowledge formalised on the ARPENTEUR Photogrammetric workstation. *The International Archives of Photogrammetry and Remote Sensing*, Amsterdam, The Netherlands, Vol. XXXIII, Part B5, pp. 187-194.

Drap, P., Grussenmeyer, P., Gaillard, G., 2001. Simple photogrammetric methods with ARPENTEUR : 3D plotting and orthoimage generation. *XVIII CIPA International Symposium, Potsdam, Germany, Sept. 18-21st, 2001.* Proceedings in print.

Drap, P., Long., L., Durand, A., Grussenmeyer, P., 2001. From underwater photogrammetry to a WEB integrated documentation system. The case study of the « Grand RIBAUD » Etruscan wreck. *XVIII CIPA International Symposium, Potsdam, Germany, Sept. 18-21st, 2001.* Proceedings in print.

Drap, P., Grussenmeyer, P., Gaillard, G., 2002. 'ARPENTEUR' as web based photogrammetric package: towards interoperability through a XML structure for photogrammetric data. *ISPRS Comm. V Symposium*, Corfu, Sept. 2-6, Greece.

Grussenmeyer, P., Drap., P., 2000. Teaching Architectural Photogrammetry on the Web with ARPENTEUR. *The International Archives of Photogrammetry and Remote Sensing*, Amsterdam, Vol. XXXIII, Part B6, pp. 102-109.

Grussenmeyer, P., Drap. P., 2001. 3D Geometric modeling from images on the WEB with ARPENTEUR. *In Optical Measurement Techniques V*, Vienna, October 1-3, 2001 /Armin Grün/Heribert Kahmen (Eds.), Special Session on Multimedia in Education, pp. 424-432.

Grussenmeyer, P., Drap. P., 2001. ARPENTEUR, a web-based photogrammetry tool. *Proceedings of SPIE, Videometrics and Optical Methods for 3D Shape Measurements VII*, Electronic Imaging and Photonics Symposium, January 21-26, 2001, San José, California, pp. 117-225.

Grussenmeyer, P., Drap. P., 2001. Possibilities and limits of web photogrammetry : experiences with the ARPENTEUR web based tool. *In Photogrammetric Week '01,* Dieter Fritsch/Rudolf Spiller (Eds).Heidelberg, Wichmann, pp.275-282.

Neusch, T., Grussenmeyer, P., 2002. Urban imagery combining photogrammetric and remote sensing techniques: a new training course at ENSAIS Strasbourg. *ISPRS Comm. VI symposium*, São José dos Campos, Brazil, , Sept. 16-20.

References from websites:

ARPENTEUR, an ARchitectural PhotogrammEtric Network Tool for EdUcation and Research; http://www.arpenteur.net (version 3, accessed July 2002).

Extensible Markup Language (XML) 1.0 (Second Edition), W3C Recommendation. eds. Tim Bray, Jean Paoli, C. M. Sperberg-McQueen and Eve Maler. 6 October 2000. http://www.w3.org/TR/REC-xml.

Ferhat, G., 2001. Working with ARPENTEUR. Virtual academy *Workshop and Seminar, FIG WG2.2*, Espoo, Finland, June 5-8, 2001, 10 pages, http://ns.foto.hut.fi/fig/FIG_Helsinki_2001_notebook/Workshop.htm (accessed july 2002).

OpenGIS Implementation Specification: Coordinate Transformation Services (Revision 1.00) Open GIS Consortium, Inc., OpenGIS Project Document 01-009. 12 January 2001. http://www.opengis.org/techno/implementation.htm. (accessed july 2002).

Photomodeler 4.0. EOS Systems, www.photomodeler.com (accessed july 2002).

Renfer, M. & Daeffler, M., 2001. ARPENTEUR, Maa-57.355 *Exercise in Imaging Technology*, 2001, Helsinki University of Technology. http://foto.hut.fi/opetus/355/harjoitustyot/renfer_daeffler/Renfer_Daeffler_Arpenteur.pdf (accessed july 2002).

XML Schema Part 0: Primer, David C. Fallside, ed., W3C, 2 May 2001. http://www.w3.org/TR/2001/REC-xmlschema-0-20010502/primer.html (accessed july 2002).

XML Schema Part 1: Structures, W3C Recommendation. eds. Henry S. Thompson, David Beech, Murray Maloney, Noah Mendelsohn http://www.w3.org/TR/2001/REC-xmlschema-1-20010502/ (accessed july 2002).

XML Schema Part 2: Datatypes, W3C Recommendation. eds. Paul V. Biron, Ashok Malhotra http://www.w3.org/TR/2001/REC-xmlschema-2-20010502/ (accessed july 2002).