The 13th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2012)
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Archaeological Field Documentation and Architectonic Analysis - a 3D Approach. Ein Zippori as Study Case.

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Abstract

A key element in any archaeological excavation is an accurate recording of the excavated material. Since the archaeological process by itself is one of destruction, the need for an accurate documentation becomes even more imperious; when dealing with rescue excavations, where in most cases sites will be completely destroyed or in the best cases covered for posterity, the problem is augmented again. Another challenge is how to obtain an outcome that will serve later on archaeologists to understand their site and prepare an accurate scientific report, and have materials ready for a comprehensive publication. The paper presents the implications, advantages and challenges on using 3D documentation at rescue excavations, as preliminary experimented at the site of Ein Zippori, Israel. These were partially developed during the 3D-COFORM project, aiming at creating affordable 3D technologies and methodologies for the Cultural Heritage sector.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Digitizing and scanning, I.3.7 Three-Dimensional Graphics and Realism, Structure for Motion.

1. Presentation of the challenge

Large archaeological bodies, in particular public institutions, such as the Israel Antiquities Authority (IAA), have to cope yearly with hundreds of excavations, covering all types over very large areas (several hundreds of square meters) to very small sites (an agricultural installation, remains of a wall, etc.). These may last for several months with tens of workers and several archaeologists in charge, to a few days and few “diggers”. In some cases external constraints (urgency to start development projects, bad weather, etc.) terminate excavations in a rather abrupt way. All these require a well-established protocol for documenting sites which has to fulfil the archaeological scientific needs (analysis and publication), but may have further implications regarding documentation sent to third parties (e.g. developers, public administrative bodies, etc.), decisions on extension of excavations and elements from the site to preserve, restore or develop for public visits. Nowadays, IAA employs a group of surveyors and artists who take field measurements (GPS, total stations) who hand draw sections, walls and built installations. These are integrated into a CAD system in order to obtain excavation plans and stratigraphic sections to be used by archaeologists during their analysis of remains and for final (paper) publications. In the last years IAA is conducting systematic pilot research and survey of new technologies and methodologies in order to improve the quality of such work and diminish related costs. The work presented below is part of such an activity, which took place during September 2012 at the prehistoric site of Ein Zippori.

2. Description of the site

The site (Figure 1) was discovered during a survey conducted by Zvi Gal [Gal02] in the end of the 1970's. It is located in the Lower Galilee, Israel, 2 km to the west of Nazareth. It extends over several hundreds of square kilometres and includes remains from at least three different periods, the earliest being several layers of occupation during the Pre-Pottery Neolithic (ca. 8,000-7000 BC), the Early Chalcolithic (ECh) (ca. 5,500-4,500 BC) and the Early Bronze Age (EB) I-II periods (ca. 3,200-2,800 BC). Byzantine (6-7th centuries AD) structures (a wine press and a stone quarry) were found as well in the area, cutting the prehistoric layers. The ECh occupation is represented by architectural remains, several types of installations and cup-marks on the bedrock [GM*11]. A large-scale site belonging to the EB I period (ca. 3,200-

DOI: 10.2312/VAST/VAST12/113-120

3,000 BC) was discovered above the ECh remains, and is represented by habitation houses, silos, installations and various architectural remains, which their purpose still needs to be elucidated. A broad wall in the eastern part of the site (ca. 2 meters broad) is probably a defence wall of the EB I town. The overall picture of the site presents an intricate puzzle of walls, many of which are built with the same techniques, pits and tons of pottery sherds, flint items and other material culture objects. The present paper which presents the results of the experiment will deal mainly with the remains of the EB I period at Ein Zippori.

Figure 1: *General over-view of the site. Photography by Skyview Ltd., courtesy of the IAA.*

The excavation method applied is often known as the Wheeler-Kenyon method [Whe56; Ken64; Cal79], where the area is divided into a grid system of 5 x 5 square meter squares, each square being excavated within the 4x4 meters limits, thus un-excavated borders between sites used for stratigraphic analysis and access of workers to their working spots (especially for removing excavated material with the wheel barrels). At a later stage, these bulks were removed, in order to have a wide overview of the excavated area. Excavation continued until virgin soil or bedrock was obtained in each square. Prior removal, all excavated remains have been drawn and an overall and inclusive AutoCAD map has been created. Additionally, extensive aerial photographs provide an overall picture of the site. GPS points have been taken in order to locate the site on the national grid system.

3. Technologies involved-the 3D acquisition pipeline

The aims of the experiment described in this article were twofold: investigate which existing technologies, equipment and software are most suitable for accurate field documentation and which is most appropriate for architectonic investigation, stratigraphy analysis, scientific visualization and spatial analysis. Two 3D acquisition methods have been tested: Structure from Motion (SfM) [SFM] and laser-scanning. Following an extensive bibliographical survey [RPV*12; Car12; DFV*11; CdUD*11; PvGV*03; BBC*10], analysis of previous results of similar work and availability of equipment, we have opted for a Nikon digital camera for the first task, while for the second a Surphaser Terrestrial Laser Scanner (TLS) has been used [LNC*09]. Acquired data has been processed with several on-line services available for producing 3D models out of sets of digital photos (including 3DCOFORM Arc3D [Arc]) and MeshLab [Mes], while further investigation into data was performed on proprietary software (e.g. Autodesk and JRC Reconstructor [SV07]). 3D outcomes will be online published using X3DOM [X3d] and 3D-PDF. Several factors were taken into consideration:

1. Availability of hardware / software.
2. Easiness of use.
3. Actual / desired accuracy of results.
4. Amount of post-processing investment.
5. Readiness of technological tools (software) for an in-depth archaeological investigation.
6. Extent of time required for data acquisition/processing.
7. Extent of time required for data investigation.

4. Implemented working methodology

Three main questions guided our field and laboratory work: which is the optimal digital data acquisition method given accuracy constraints (set up to a maximal margin error of a few cm) and time limitations, what are the available software for a throughout analysis of the acquired data and how we publish such data for further analysis (addressing the issue of primary data transparency) for further scientific investigation and in order to comply with legislative requirements (full archaeological report). Our goal was to define a workflow that would allow archaeologists to apply a 3D approach for: data acquisition, a (daily) 3D excavation diary, a 3D environment for investigation of excavation results and how to publish such results in order to be made available for scientific evaluation and re-use as well as compliance with legislative constraints.

We have decided to opt for two methodologies for data acquisition: laser scanning for the large-scale exposed areas with extensive and intrinsic architectural remains, and SfM, for the documentation of the on-going excavations in individual squares, aimed the creation of a 3D excavation diary of the site and documentation of the excavated remains. The outcomes of both techniques were then compared and their efficiency evaluated against the criteria presented above.

An area of 1500 square meters, dug to a depth of ca. 2 meters has been digitally acquired with the phase-shift Surphaser 25HSK TLS. Preparatory work included positioning of twenty targets along the borders of the excavated layers, to be used as common points for aligning together the multiple scanning episodes and estimate the number of scanning episodes needed in order to cover the entire area. Due to the depth of sediments and complexity of remains, 11 scans needed to be acquired along the circumference of the selected area, at distance of 3 to 10 meters from target. Each scan took ca. 3 minutes (ca. 1 million points per second), the entire acquisition stage of a

150x10x2 meters area was completed in less than one hour (including preparatory work). Once scans have been completed, they were aligned using MeshLab software. The alignment process took ca. two hours of laboratory work. The obtained file included ca. 1,5 million vertices and ca. 11 million faces, the meshed file having a weight of ca. 200 Mb. The accuracy of measurement obtained had a maximum error of 0,5 cm.

The area chosen for the SfM three adjacent squares, dug to a depth of ca. 1,5 m each. Each square was photographed in two episodes distanced in time over 48 hours, in order to document the changes in the excavation layers occurring during this period. 45 photos, taken along the circumference of each square's borders at ca. 1 meter distance from the square and focusing on the same spot proved to be sufficient to cover the entire investigation area. The whole process took ca. 5 minutes of data acquisition per square, at a resolution of ca. 4x3 thousand pixels with a Nikon AF-S camera with a fixed-focus lens at 24 mm. Each photo weights ca. 5 Mb. Data was processed with Autodesk 123D [123] for the creation of the meshes, resulting in an .obj file of ca. 50 Mb per square and meshed with MeshLab software. The density of the obtained meshes was within 0,5 cm between vertices. This process took ca. two hours, depending on availability and speed of Internet connection (123D being a web-based service for transforming sequence of images into 3D point-clouds). Targets were fixed along the borders of the square, in order to facilitate the automatic alignment of the photos and to obtain a scalable 3D model (the distance between targets was manually measured).

5. Analysis of results

Since essentially any excavation process is a destructive one (at the end of a rescue excavation usually there are no archaeological remains left for a future analysis, unless specific protective measures are taken place) it is imperative to accurately document this destroying process, in order to obtain an outcome that can be used for scientific analysis during the intellectual process of interpreting the archaeological remains and to archive it for future research. Actually, nowadays an interesting paradox occur in standard archaeological investigation, where remains are examined outside their original context, which is partially reconstructed in the mind of the archaeologist (if it is the same archaeologist who excavated the site and its visual memory is reliable), or from 2D plans, drawings and usually not-rectified images, with un-balanced colours. Thus, one of the most important human senses, from which most information about surrounding environment is absorbed and processed, i.e. the vision, is used to a very limited extent when analysing the archaeological context of finds and their content (e.g. architectonic remains).

Typical archaeological questions that may be answered through the analysis of 3D documentation outcomes may be divided in two groups:

1. Analyses performed in order to understand the stratigraphic complexity at the site; these include:
- Virtual separation of layers, features or walls.
- Cross-sections at any desired position, from any desired angle.
- Estimate which remains are contemporaneous with which.
- Understand the dynamics of site's destruction process (along a long time, natural decay or following a disruptive event, be it natural or anthropogenic).
2. Interpretation of results needed to understand the past uncovered; these may include:
- Accurate spatial measurements.
- 3D virtual extension (continuation and completeness) of walls in order to understand their spatial inter-relationships.
- Visually interpretation of spatial distribution of features and finds.
- Inter and intra simulation of structures and their content (e.g. furniture, construction material, illumination, etc.).
- Structural analyses and statics of reconstructed structures.

The results published herein focused on investigating how 3D documentation may answer the first set of question, as a digital tool for planning next excavation stages and the preparatory steps needed for a throughout and comprehensive interpretation of the archaeological site.

6. Post processing of 3D dataset

6.1. Laser Scanning

The TLS point clouds were aligned in JRC 3D Reconstructor. There are in general two ways to align more scans between them (Pre-registration way using target) and (Geo-referencing way using coordinates taken by total station or GPS). In this case study it was used the Pre-registration way, (a set of targets have been put to the ground, so as to be able to recognize common points in the Post-processing phase. This technique allows us to manually compute a rough alignment between two grid point clouds (Scan position). The alignment can be later refined automatically, using ICP registration. The Pre-registration procedure works by finding three couples of corresponding points among the reference and moving grids. When three or more couples of points are selected, an automatic algorithm calculates the alignment error per point couple. This is the first step to be used for the alignment of two scans, in our case, in which we have more scans, after performing a first alignment having a determined error we must use another automatic algorithm: (ICP) Iterative Closest Point. The algorithm finds points on the moving cloud that are close to the reference clouds (the first point cloud that we have chosen to align all other). These points are called control points. The algorithm then iteratively moves the moving cloud to reduce the distance of the control points to the reference models. After each step of movement, the control points are recomputed and aligned much better reducing the error between the different scans.

After the alignment of the point clouds, images were registered on the point clouds, using camera calibration tool. The outcome is a photo-realistic texture maps for the 3D model. The process is:

- Load a picture which reflects the same view of the point cloud to obtain an easier recognition of points and a better overlapping image of the model itself. Select no less than 11 common points between the point cloud and the image so to stretch latest on 3D data. After at least 11 marker pairs are found between the photo and the grid the new re-projection and a new camera are created.

Load the mesh, already previously created from the point cloud, load the new Re-projected camera of the image and start the virtual scan command, from which we obtained a new textured point cloud [Neu07; BM11].

The TLS outcome, after alignment of all scans and application of texture with camera calibration tool (Figure 2), produced a point-cloud that served for features measurements, including sizes of stones used as building material, type of mortar or depth of sediments (Figure 3).

Figure 2: *3D point-clouds with texture. EB I building, Area C.*

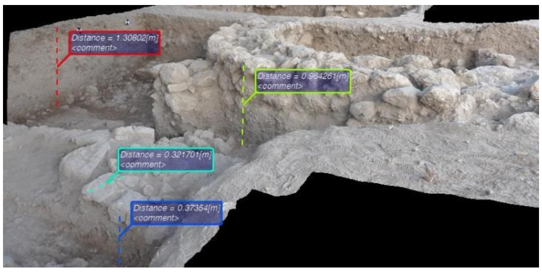

Figure 3: *3D model with annotated measurements.*

A consequent step was separation of features belonging to different cultural/temporal episodes. This was done by selecting borders of features to be extracted and presented separately. This step enables a clearer view of each homogenous anthropogenic episode and its analysis separately (Figure 4).

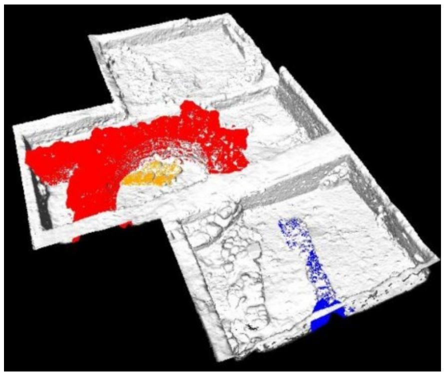

Figure 4: *Visualization of anthropogenic layers.*

Consequently, polylines can be drawn along features of interest, which can be later exported and integrated into a CAD system (Figure 5).

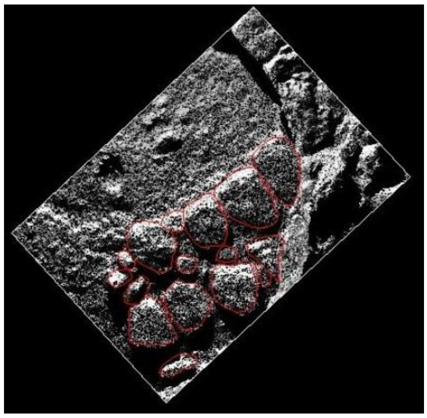

Figure 5: *Polylines drawn on the 3D point-cloud.*

Since during the excavation many aerial photos have been shot (Figure 6), an interesting exercise was to try and rectify them according to an orthophoto obtained from the top view of the point cloud and its rectification (Figure 7).

The orthophotos from 3D model has been created by inserting orthogonal planes on the model and by the creation of orthogonal views, from which are obtained ortho-rectified images. The images are saved and a text files are created from the image files, which exports the information of images registration and coordinates in the ortho-scene. This text file can be imported into Auto-CAD and here can be digitized with polylines. Several options are available to export ortho-photos in AutoCAD: a plain 2D image, or whether also the 3D position and orientation that the image has in Reconstructor as current UCS should be exported to Auto-CAD. It is also possible exporting in Auto - Cad the image's 3D pose, which is useful if other items, as sections are related to the same model

Concerning export of data in AutoCAD, from JRC 3D Reconstructor software, can be exported: sections, images, plans, ortho-photo and a few limited point clouds in .txt or .ascii points format. A limitation of AutoCAD in this sense is represented by reading and managing millions of points without which the system is slowed down or crashes. A very good alternative to reduce these problems is represented by the use of plug-in PointCloud for Reconstructor.

PointCloud plugin allows managing 3D laser scanner data within AutoCAD. In addition to the management of billions of points, provides a set of functions that facilitate and speed up the analysis of point clouds in AutoCAD, developed for the elaboration of the point clouds, for advanced modeling and clash detection. This plug-in allows working with the vast majority of data from the scanner.

Figure 6: *Aerial photo of selected features. Photography by Skyview Ltd., courtesy of the IAA.*

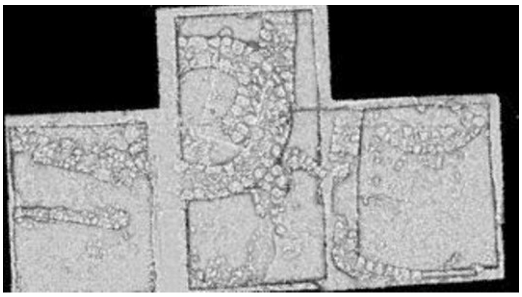

Figure 7: *Orthophoto from 3D mesh.*

This step enables to "recuperate" important information that is stored in previous documentation campaigns and integrate it with the 3D data. Moreover, rectified orthophotos may be easily used for traditional, paper publications.

6.2. SfM

The SfM technique allows automatic reconstruction of 3D geometry of a scene from 2D projections of multiple uncalibrated images. It was tested in three adjacent squares, in two separate episodes distant two working days from each other. Every square was separately documented, thus we obtained 3D meshes of each one separately (Figure 8). Each was scaled according to a previous measurement of distance between target points recognizable in the 3D mesh.

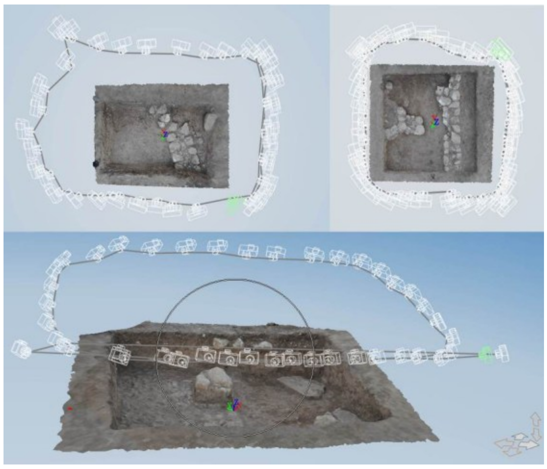

Figure 8: *SfM 3D* meshes, *EB remains, Area G.*

The next step was to align the square together, according to the identification of shared target points in each mesh (Figure 9).

Figure 9: *Alignment of separate meshes.*

Once the full 3D model of the interested area was obtained, analysis may proceed following a similar line as the laser-scanning product. By overlapping 3D models of the same area, registered in sequent time periods, it was possible to 3D register and document the archaeological excavation process and obtain an outcome that can serve as a reference point for investigation of archaeological results.

6.2.1. Quantitative analysis

The assessment of final accuracy is carried out by analysing the level of agreement between the 3D model obtained from the SfM and the generated 3D model with the TLS, using

CloudCompare 3D open source software, developed by the research department of EDF (France) [Clo].

Since both dataset contain a different resolution (350 thousand faces and 150 thousand vertices for SfM and 4 millions of points for TLS), an effective comparison is performed based on sampled point tool of the mesh.

The SfM 3D model was scaled using targets placed on the borders of the excavation (Figure 10) previously measured. The same targets and some discernible features were used to register the two dataset (SfM and TLS) in MeshLab, with alignment error of 0,3 cm.

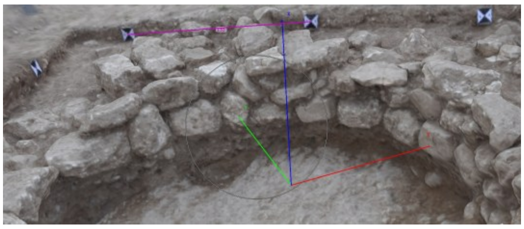

Figure 10: *Mesh scaling procedure using targets. EB I building, Area E.*

In CloudCompare the TLS point cloud and the SfM sampled point cloud from the mesh were compared using distance computation tool (Figure 11).

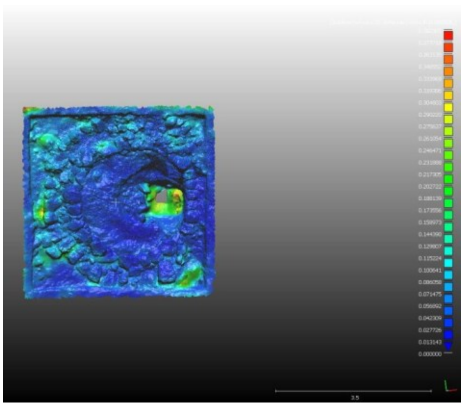

Figure 11: *Error mapping of distances taking the TLS point cloud as reference.*

The standard deviation of the error has been computed to 0,75c m. On the histogram of the error the 96% of the points have an error 1.6 cm (Figure 12).

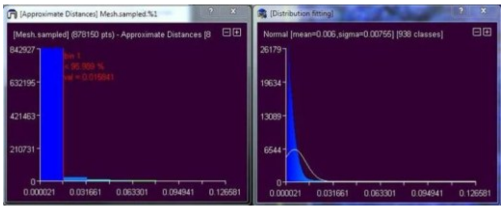

Figure 12: *Histogram of relative accuracy*

The highest errors, from 4 to 7 cm, reported in green (Figure 11) were originated because of there was not enough space to keep the correct distance and in some cases the whole object did not fit inside the frame of the camera. This problem could be solved easily using a wide-angle lens, although wide-angle lens accentuate the apparent perspective distortion.

7. Summary and conclusions

Applying 3D documentation methods in the documentation of archaeological remains has not yet reached the stage of a well-implemented protocol, with well-defined stages, measures to adopt and tools to work with. Software development, in particular tools for manipulating 3D data, has been oriented towards optimization of processing point clouds, creating meaningful meshes and various visualization filters. One of the aims of this work was to investigate how existing technologies can be integrated into creating a pipeline that would enable and facilitate the analysis of 3D data from archaeological remains. In other words, how to match between archaeological expectations and existing technologies, in particular some of those developed during the 3D-COFORM project.

SfM, represented by the Arc3D web-service, proved to have lower performances when compared to similar initiatives, such as Autodesk 123D or Agisoft PhotoScan [Agi]. This is mainly due to the long time-consuming between uploading the images and receiving the 3D mesh, failure to create meshes in several cases and un-availability of service in some occasions. When all was smoothly functioning, Arc3D return satisfactory results, comparable in quality with Autodesk 123D and Agisoft. Moreover, Autodesk 123D and Agisoft PhotoScan proved to be much more user friendly and intuitive than Arc3D. Summing up, main expectations from data acquisition techniques are: accuracy of outcome (which may vary according to aim of work and type of acquired object), easiness of use and time consumption. In this perspective, SfM proved to be a fast and easy to use approach for recording excavation areas that do not exceed 100 square meters, at an accuracy level not exceeding 2 cm., an accuracy that is well within the tolerance range of any traditional archaeological measurement and has no influence or negative impact on the analysis of results.

One of the major advantages of laser-scanning technique is the acquisition range, which in the case of the device used (Surphaser), located in the centre of the area of interest, covers a maximum area of ca. 20 meters in each direction and 10 meters in depth, in a very short time (ca. 5 minutes). The complexity of the archaeological remains, the accessibility to interested area and the level of detail needed may require multiple scanning from different positions, in order to assure a full coverage of remains. The return is a very accurate registration, through a relatively easy to use and intuitive process. Still a major inconvenience consists of the very heavy files generated by laser-scanning recordings. The gradual hardware performance improvement may be also supported by a technological investment in reducing file weights and in the same time keeping high the accuracy level.

The post-processing of acquired data follows similar steps for both documentation techniques. A major difference is in the much longer time employed in the aligning laser-scanning data, when compared to the SfM files. Moreover, laser-scanning data needed to be "cleaned" from unwanted "noise" information and later on simplified (in order to cope with hardware performance limitations). MeshLab proved to be an ideal tool for processing acquired data and basic analyses from an archaeological perspective. However, its interface is not particularly intuitive and lacks some basic features needed for an archaeological investigation of the meshes / point-clouds.

A major challenge for future technological research would be the development of an open-source solution adapted for an in-depth archaeological investigation, i.e. a tool-kit for archaeologists aiming at investigating their 3D data. These would include:

1. Measurements along any shape of surface, from one point to the other, curvatures, etc.,
2. Slicing the 3D point-cloud along a desired (irregular) plane
3. Continuation of geometry (e.g. for hypothesizing orientation and shape of walls).
4. Comparison between features (already existing).
5. Easy and lossless transformation of point-clouds into a CAD format.
6. Semi-automatic extraction of polylines along features of interest from acquired data (e.g. separating wall stones).

Future research will include the systematic investigation on the impact of the distance from target and camera zooming on the accuracy of the registration.

Acknowlegments

The authors are indebted to the IAA for the logistic support given during the 3D pilot project and for the permission to publish the aerial photographs of the excavation. This research benefited from the support of the EU-funded project 3D-COFORM (www.3dcoform.eu).

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