

STUDY TO PROTECT MICHELANGELO'S DAVID FROM INDOOR AIR POLLUTANTS

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Introduction

Every year millions of people visit the works of art placed in museums, which aren't the safest place to protect cultural heritages from air pollutants.

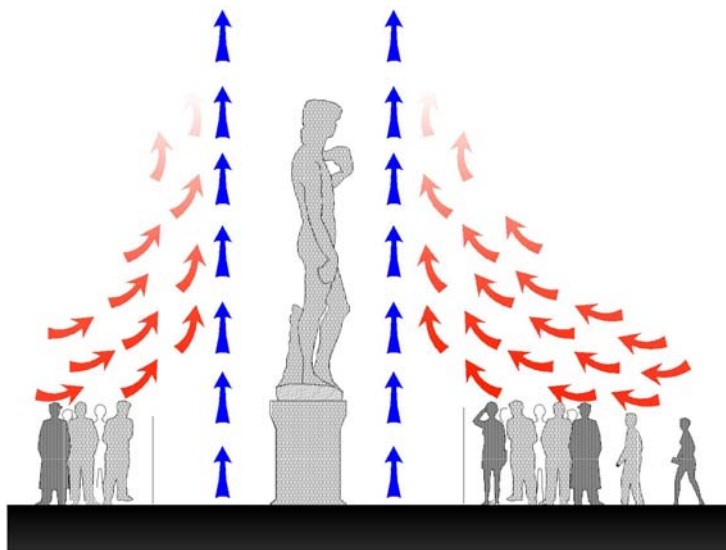


Fig. 1 - A proposal for direct protection method against visitors pollutant

The use of air curtains may often represent a protection for the cultural heritage without operating on the material of the objects, and without limiting the perception of the work of art¹. The aim of this work consists in the characterisation of this device widely used in industry, but not frequently adopted yet in the field of conservation of works of art. As a matter of fact the employment of air curtain to segregate pollutants diffusion near the sources for fire prevention is actually more and more diffused in industry buildings [1,2,3,4,5,6,7,8]. Their success is due to the peculiarity to separate zones without fixed barriers which should interfere with people and equipments. The application of air flows in museum deals with the problem to separate visitors and objects in order to protect the latter from pollutants.

When the device is installed near the object to protect, this represents a "direct protection method", and a study of this kind of system is on to go in the air distribution system of the

¹ "this is why, the first step to be considered, will be not on the material of the object directly, but simply oriented to reach the necessary conditions for asserting it within the space of existence" "teoria del restauro", Cesare Brandi

Galleria dell'Accademia in Firenze where Michelangelo's David and other masterpieces are placed in (Fig. 1)[9].

When a decontamination treatment of the visitors is provided, by means of an air curtain system able to remove at the entrance of the people most of their potentially dangerous pollutants, an "indirect protection method" is defined. An ongoing research of the latter is presently studied in the Museum of the Rocca di Vignola (Modena) to remove pollutants from visitors of the fresco painted chapel².

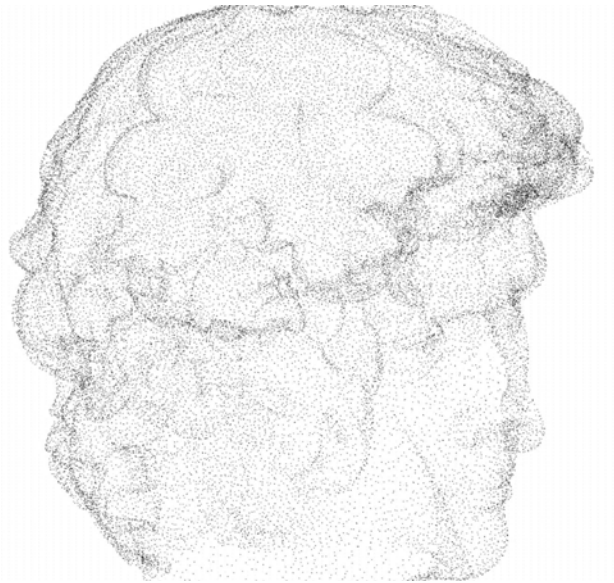


Fig. 2 - The cloud of point

Modelling related problems to mesh statue and museum environment

The first step deals with the modelling related problems of a volume mesh representing the space where the statue is placed, to simulate the existing fluidodynamic regime. The model of the air distribution system, allows to characterize the risk zones in the surrounding environment of the statue, where air pollutants may concentrate. Once the fluidodynamic regime is characterized, a study of the available solutions to protect the statue can be finally settled up. Examples of such a procedure have already been presented [10][11].

Different modifies of the existing air distribution system, mapping several air curtain configurations, are tested with the CFD code to evaluate the solution to the dust deposition problem on the statue surface.

The modelling step of these research, starts with the preprocessig of the cloud of points of the David surface that is obtained with reverse engineering technique [9]. The starting density of this points cloud (Fig. 2), with distance between points of less than 2.5 mm, is too high to be adopted as a boundary for the complete model of the museum which has a nave 38 m long. Improvement of density of the cloud of points as high as possible, according with the museum dimensions and calculation facilities has been carried out. Being the number of cells of the

² "Progettazione impiantistica e rilievi microclimatici per la conservazione degli affreschi della Cappella di Ugucione Contrari, castello di Vignola, Fondazione Cassa di Risparmio di Vignola.

volume mesh in the first layer that cover the statue about three times the number cells placed on the boundary surface, the final distance between points of the statue, after the filtering treatment, has been chosen of 40mm.

Once obtained the right density, the surface of the statue is created using the tassellating command to cover the greatest part of the cloud of point, while the remaining holes in the surface are closed manually (see Fig.3) [12].

The complete surface of the statue can be exported from the tessellating software to the preprocessing software Gambit® in order to create out of it the museum environment model

At this step the topology of the surface imported (as an Stl file) presents a relationship between points, edge and cells often not correct. It may occur, for example, that a point belongs to the end of an edge without being a part of the cell, or that two bounding cells haven't the same edge. These topology problems don't allow the creation of the final volume mesh. And they may be corrected efficiently out of the pre-processor software Gambit®.



Fig.3 - The cloud of points tassellated contains holes that have to be manually filled

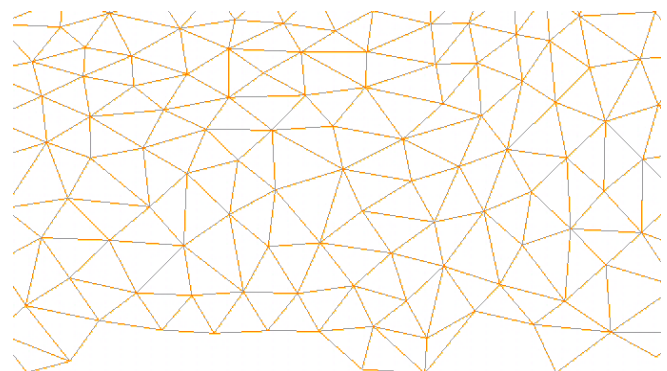


Fig. 4 - The irregular edge of the mesh surface

If a correct statue surface topology is obtained, an environmental model have to be built starting from the irregular edge of the statue at its base.

The points of the edge of the statue don't belong to an horizontal plane (Fig. 4), being difficult to link it to the regular geometry of the base of the statue. These two edges can be connected only by a manually built ring, taking care to its topology (see Fig.5).

Once the statue is linked to the base, all the boundary museum surfaces can be created to obtain a complete volume of indoor air environment.

Before to start the creating process of the volume mesh, adopting the opportune size function, it's important to check the characteristic of the surfaces mesh: triangles that arrange the mesh

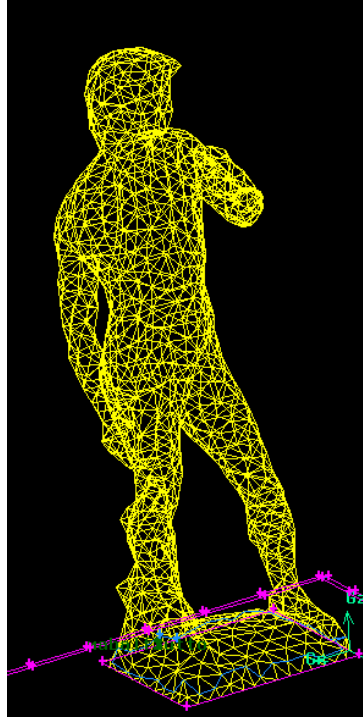


Fig.5 - The surface mesh statue is manually linked to the base

have to be as similar as possible to the equilateral, maintaining a gradually changing size.

Aspect ratio, equiangle skew and equisize skew, allow to check the characteristics of the mesh surfaces.

The aspect ratio for triangular and tetrahedral elements Q_{AR} is defined as [13]:

$$Q_{AR} = f \cdot \left(\frac{R}{r} \right)$$

where f is a scaling factor, and r and R represent the radii of the circles (for triangular elements) or spheres (for tetrahedral elements) that inscribe and circumscribe, respectively, the mesh element. For triangular elements, $f=1/2$; for tetrahedral elements, $f=1/3$.

By definition $Q_{AR} \geq 1$, being $Q_{AR}=1$ in the case of equilateral element.

The equiangle skew Q_{EAS} is a normalized measure of skewness (Fig. 6) that is defined as follows:

$$Q_{EAS} = \max \left\{ \frac{\theta_{\max} - \theta_{eq}}{180 - \theta_{eq}}, \frac{\theta_{eq} - \theta_{\min}}{\theta_{eq}} \right\}$$

where $\theta_{\max}$ and $\theta_{\min}$ are the maximum and minimum angles (in degrees) between the edges of the element, and θ_{eq} is the characteristic angle corresponding to an equilateral cell of similar form. For triangular and tetrahedral elements, $\theta_{eq}=60^\circ$

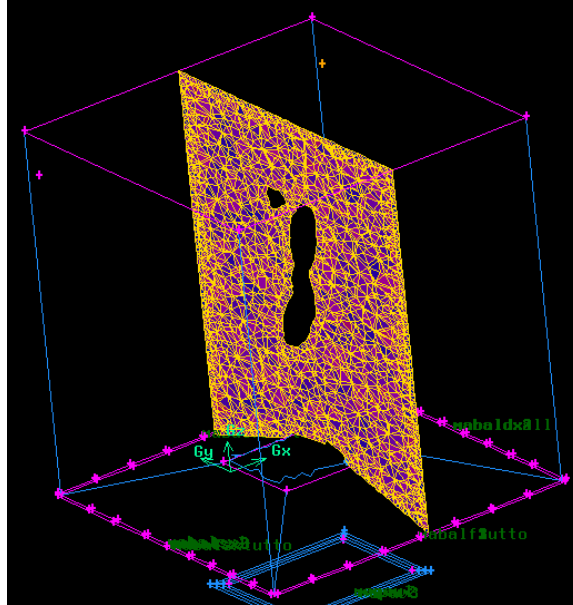


Fig. 6 - A sliding plane with the quality of the mesh associating a value of the skewness to the color displayed

By definition: $0 \leq Q_{EAS} \leq 1$, where $Q_{EAS}=0$ describes an equilateral element, and $Q_{EAS}=1$ describes a completely degenerate (poorly shaped) element.

The verifications that meshes contain elements that possess average Q_{EAS} values of 0.1 (2-D) and 0.4 (3-D) has been performed.

The equisize skew (Q_{EVS}) is a measure of skewness that is defined as follows:

$$Q_{EVS} = \frac{(S_{eq} - S)}{S_{eq}}$$

where S is the area (2-D) or volume (3-D) of the mesh element, and S_{eq} is the maximum area (2-D) or volume (3-D) of an equilateral cell the circumscribing radius of which is identical to that of the mesh element.

By definition: $0 \leq Q_{EVS} \leq 1$ where $Q_{EVS}=0$ describes an equilateral element, and $Q_{EVS}=1$ describes a completely degenerate (poorly shaped) element.

High-quality meshes contains elements that possess average Q_{EVS} values of 0.1 (2-D) and 0.4 (3-D).

These features can be checked with an inquiry command of Gambit® software, which displays only those mesh elements which have the above reported geometric parameters within specified limits respecting a designated quality criterion. It's also possible to display the single worst element in the mesh based on the currently selected criterion to detect critical area for the mesh processing of the surfaces.

When a closed boundary mesh surface, that respect the quality criterions, is created, the volume mesh processing can be started, adopting, in this particular case, a tetrahedral mesh. Also the volume mesh has to be regular as the surface one, as a matter of fact may occur that from a regular boundary surface mesh, an irregular volume mesh is obtained. Testing different mesh sizes, and different size functions a controlled volume mesh created. A low size of the tetrahedral mesh is chosen near the statue, rising far away from it, in order to have a more

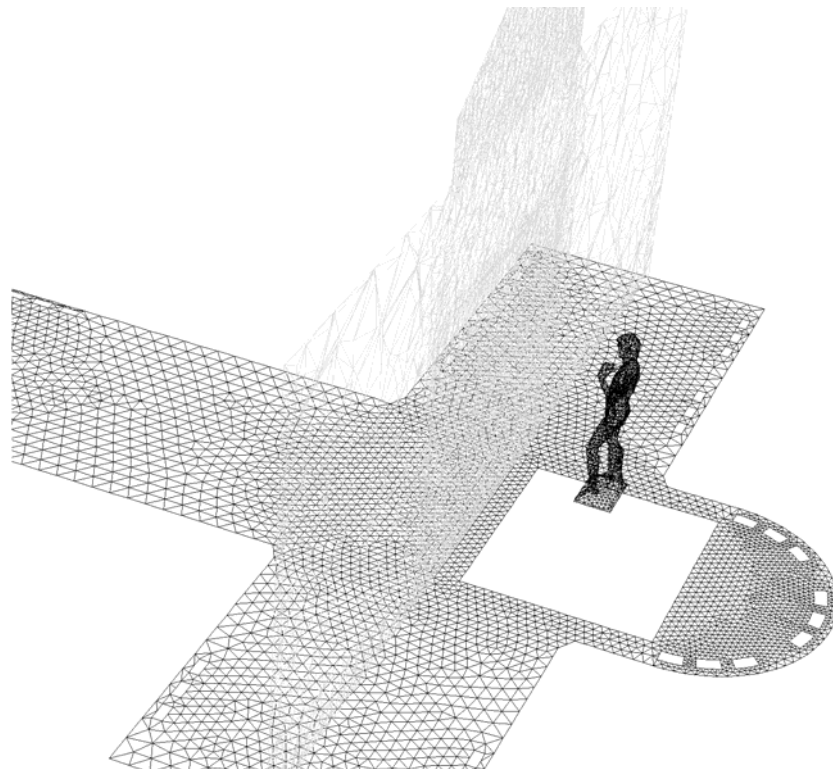


Fig. 7 - The complete mesh of the museum and the statue of the David

accurate solution of the fluid dynamic problem near the statue (Fig.7).

CFD further development

Once the model is completed, the CFD code can be applied to simulate the existing fluidodynamic regime in the indoor environment of the museum, in order to evaluate the risk zones and relationships between the pollutants sources and the object to protect. A steady state is chosen to map the velocity and pressure field near the statue neglecting convective and irradiation phenomena, not relevant in the nearness of the statue where the air distribution system outlets are placed.

Bibliography

- [1] A.Strongin, E.O.Shilkrot, *The Basic Principles for calculation of air curtains in industrial buildings*, 7 In *Proceedings of the congress Clima 2000, Naples Italy 2001*
- [2] ACGIH, *Industrial Ventilation: A manual of recommended practice*, 22nd Edition, pages 70,85 ACGIH, Cincinnati -Ohio, 1995

- [3] F. Cumo, P.P. Dell'Omo, L. de Santoli, L. Fontana, *Studio sperimentale di una lama d'aria ad ugelli per la compartimentazione di ambienti soggetti ad accidentale rilascio di inquinanti gassosi*, XIX UIT Congress, Vol1 pp451-453, Modena, Italy 2001
- [4] F. Gugliermetti, L. Santarpia, *A phenomenological approach of shutter type air curtains*, Proc. Of Air Pollution 99, VolII, pp.124-127 S. Francisco, 1999
- [5] T. Hayashi, R.H. Howell, M. Shibata, K. Tsuji, *industrial ventilation and air conditioning*, CRC Press, Boca Raton, FL 1987,
- [6] Heinsohn R.J., *Industrial ventilation: engineering principles*, John Wiley and Sons, New York, 1991.
- [7] K. Green, *Energy saving for industry, Heating and Conditioning* 57 (2), 1987
- [8] S.V. Patankashar, *Numerical heat transfer and fluid flow*, Hemisphere, N.Y., 1980
- [9] S. Bracci, F. Falletti, M. Matteini, R. Scopigno, *Exploring David*, Firenze, 2004
- [10] M. Laura Santarelli, S. Albero, *CFD modeling as analyzing method for the conservation studies. A case study: the Domus Aurea in Rome*, Proc. of IAQ 2004 in museum, Padova
- [11] A.A.V.V., *Modélisation des écoulements et transferts de masse et de chaleur à Lascaux: apports à la gestion microclimatique du site*, In "L'art avant l'histoire: la conservation de l'art préhistorique. 10es journées de la Section française de l'institut international de conservation, Paris, 23-24 mai 2002", Section française de l'IIC (SFIIC), Champs-sur-Marne - France, 2002
- [12] *Catia Users Manual, Version 5.11 Release 11*,
- [13] *Gambit 2.1 Documentation*