From the virtual model to the archaeological world: The challenge of the predictive computational models

Franco Gugliermetti

Department DIAEE – Technical Physics

Faculty of Engineer

University of Rome Sapienza,

Rome, Italy

Abstract

The predictive computational models are one of the latest applications in the world of ICT for cultural heritage; they study and represent the environment through the numerical/geometrical resolution of complex mathematical equations that regulate thermal, visual, acoustic, fluid dynamics phenomena.

The latest generation of predictive methods, with their friendly interfaces, have gradually reduced the archaeologist's sense of strangeness with these techniques to such an extent that in some cases they could represent an essential "tool" for their work and the common platform for discussions with other professionals involved in the preservation, valorisation and enhancement of cultural heritage.

This paper shows how the predictive models can intervene in the activity connected to the conservation and valorisation of cultural heritage.

Keywords: predictive models, numerical/geometrical resolution, ICT, cultural heritage, valorisation, conservation

Introduction

The diffusion of archaeological predictive models has been progressive and to some extent unpredictable when they were first introduced and seen with some diffidence: simple forecasting and design tools, intended primarily for architectural / engineering solutions related to the conservation of cultural heritage (coverings , microclimate, lighting, ventilation), or as mere exercises, often completely isolated from any historical, anthropological and archaeological approach, by which to demonstrate the scientific basis of "running" an ancient reality. The archaeologist's sense of strangeness with the predictive techniques is now gradually decreasing, so much so that in some cases they could represent an essential "tool" for historical interpretation, conservation and valorisation in the archaeological world.

The predictive computational models received a significant boost from the improvement of their reliability, the increased of CPUs computational power, the use of more "friendly" interfaces, the development of virtual reality techniques suitable to increase comprehension and interpretation of numerical results.

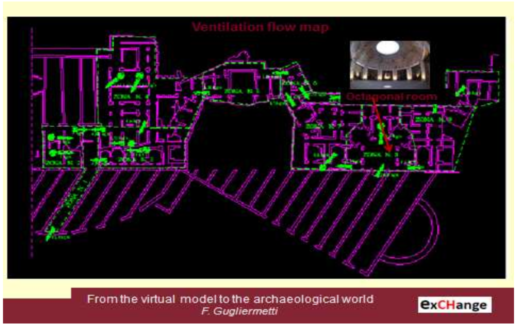
The computational models can be used to simulate thermo-fluid-dynamic phenomena, visual and acoustic fields with different scales and details. The models' fluid dynamics (CFD) can represent both static and dynamic phenomena, even in critical situations such as fire smoke or pollutants; the reconstruction of the sound field makes it possible to protect ancient and fragile structures from vibrations generated by the amplification equipment used during performances; recreating the visual environment makes possible virtual tours into the space under different conditions of natural and / or artificial light, and reduces damage to cultural and historical works subject to luminous radiations.

The current package for calculating thermo-fluid-dynamic, acoustic and lighting typically includes the possibility to directly import the geometry of the studied environment by CAD (Computer-Aided Design); the creation of the numerical model can be further simplified by "vector transformation" of 3D laser scanner architectural surveys. The potential of such a tool should not be ignored by all those who deal with issues of research, diagnosis, conservation and valorisation in the field of cultural heritage on a daily basis.

After a brief discussion of the methodologies used to solve the complex relationships that govern the thermo-fluid-dynamic, acoustic and visual phenomena, some predictive applications for cultural heritage are reported with the objective of making it easier to understand the potential of advanced computational models, with their limitations and their complexities.

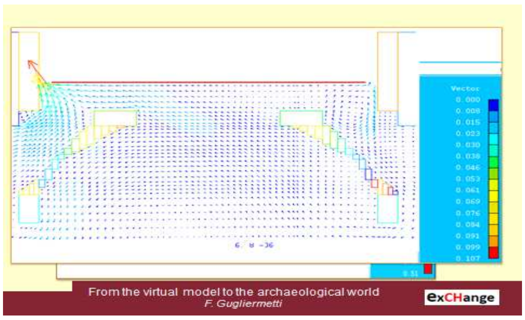
The thermo-fluid-dynamic environment

The solution of complex differential equations that are the basis of thermo-fluid-dynamic phenomena is carried out numerically, as it is not usually possible to obtain a direct solution (analytical expression of speed, concentration, pressure, etc.). The numerical method is based on the "discretisation" of the domain of calculation in a number of elementary volumes for which quantities of interest, averaged over the volume and related to its centre of gravity, are calculated so as to reach a solution for points. The size of the control volumes can be chosen: small as to allow single turbulent eddies to be studied in detail (field models or CFD model); or large as to coincide with a large portion of the studied environment (zonal models). The zonal models, unlike field models, do not require substantial computing resources and can operate on very large domains.

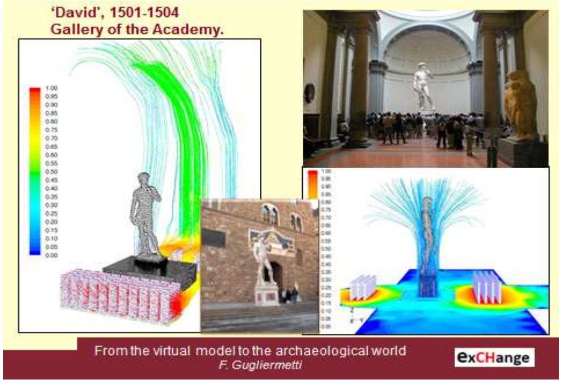


The Figure on the left indicates the results of a zonal simulation used at the end of the 1990's to study "Domus aurea" in Rome, prior to its opening to the public, to predict the possible environmental changes due both to the planned restoration (recovery of accesses, external openings, use of transparent protective roofing, etc. ..), and to the presence of visitors.

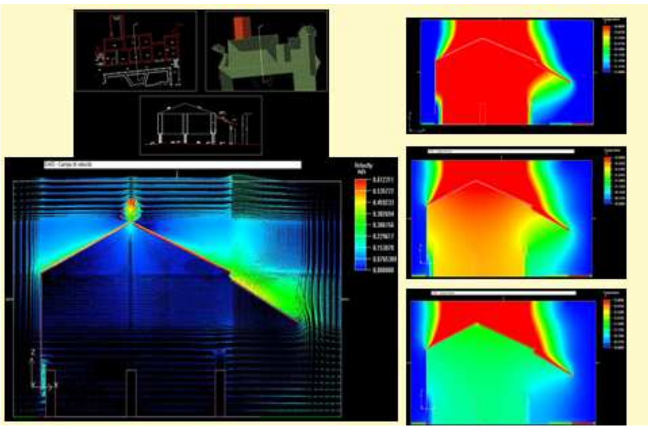
The aim was to guarantee the best conditions for the conservation of the archaeological site, which appeared to be particularly vulnerable, inasmuch as it is totally underground. In this simulation every room in the "domus" coincided with a "discretisation volume"; air flow, concentrations of effluents from visitors (carbon dioxide, water vapor, etc.) and temperatures and relative humidity in various outdoor weather conditions were calculated. The use of all this information determined the maximum load of daily visitors compatible with the proper conservation of the site and works contained therein.



the Figure on the left indicates, for the Hall Ottagona of "Domus Aurea", speed field vectors (calculated with a "discretisation" in cubes of side 0.05 m and by a CFD model) in summer conditions that would be created by the use, for protective purposes, of a transparent closure installed in the opening on the top of the dome.

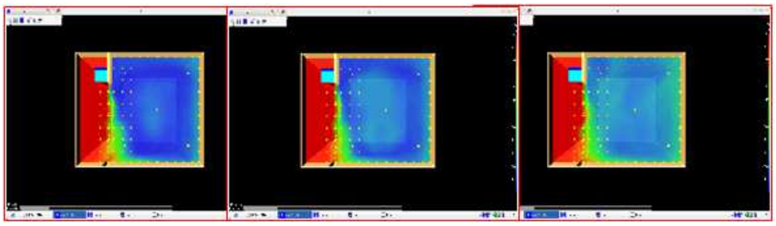


The simulations reported in the previous figures are however difficult to read since they utilise a rather "austere" and minimalist interface, which reflects the standard output of the 1990's; instead up-to-date models allow more easily understood representations, as reported in Figure 3 (on the right), related to the "musealisation" of Michelangelo's David in the Academia Museum of Florence , after its removal from the "Piazza della Signoria" to the Academia Museum of Florence; a forced ventilation system was implemented to prevent the accumulation of dust raised by the expected high number of visitors.



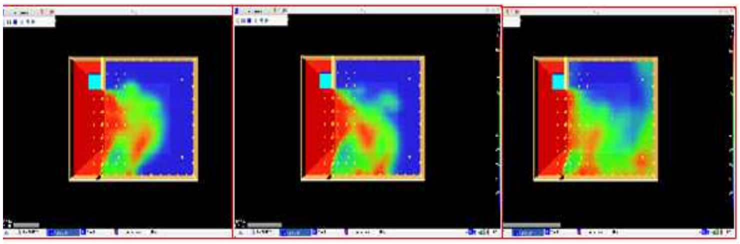
The Figure on the left instead indicates the thermal and velocity fields for different solutions to replace the existing covers in Perspex and glass used in the UNESCO archaeological site at Villa del Casale (Piazza Armerina, Enna) in order to ensure its preservation (micro-flora and salt crystallization controlled by natural microclimate conditions) and accessibility.

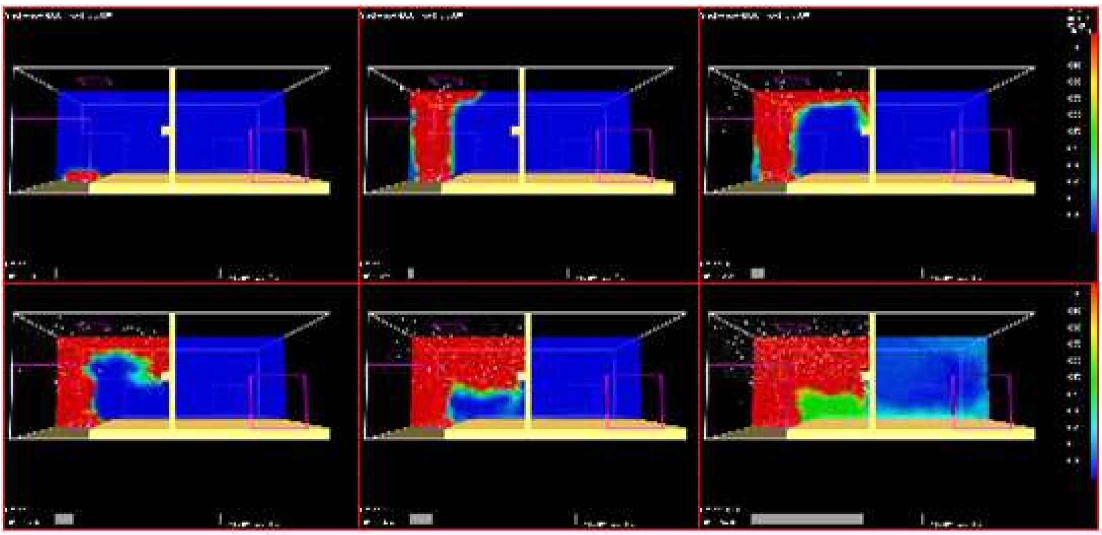
Normally the thermo-fluid fields, after an initial transition period, reach equilibrium conditions when the influences of the external environment (the boundary conditions) do not vary over time; calculation models can therefore be oriented to the stationary solution (static simulations), as the examples so far reported, or to dynamic study in which the physical quantities vary over time. The dynamic simulations generally required a great amount of calculations compared to the steady ones.



The Figure on the left shows a few frames of the dust diffusion, towards the Sistine Chapel, from the entrance.

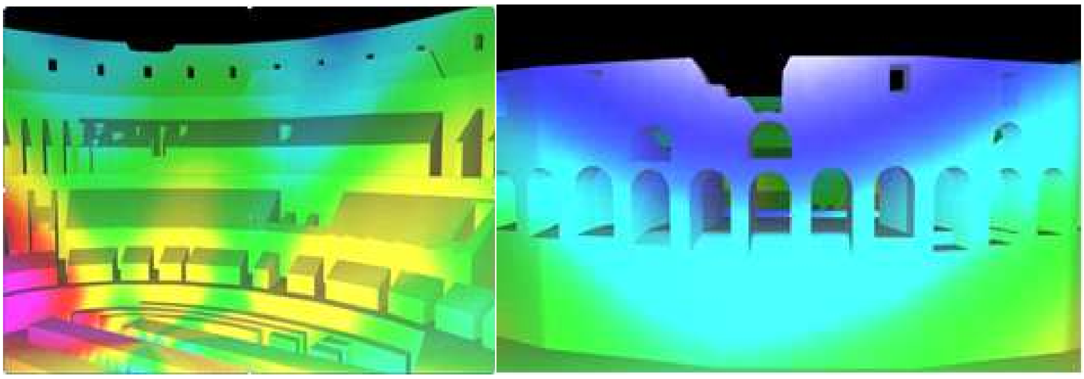
The Figure on the right represents the case in which, in order to reduce the flow of contaminants, the two environments are virtually separated by an "air curtain" located just above the access to the chapel. Regarding the field of dynamic simulations, the Figure below shows some frames referring to the concentration of combustion gas produced by a fire developing in the entrance zone of Sistina Chapel while an air curtain system is functioning. The Figure on the left shows a few frames of the dust diffusion, towards the Sistine Chapel, from the entrance.





The acoustical environment: models

The predictive models of acoustic fields, in most cases, do not resolve the complex differential wave equations as many wave phenomena, since the interference and diffraction, very often do not decisively affect the result: this is especially true with large environments where typically there are few and well localized sound sources and the acoustic field depends in large part on the phenomena of multiple reflections on the walls, making it possible to study the sound field by the simple laws of geometrical propagation. In this last case the predictive models follow the propagation of each sound beam emitted from the source in its path to the listener with all its reflection and absorption on walls; on the basis of the energy associated to each beam and its time of arrival, at any point the sound level over time (echogram) can be calculated. This geometrical approach therefore does not reproduce the phenomena of interference and resonance, while scattering (diffusion and diffraction) can only be simulated in an approximate manner.
The reconstructed sound field, on the basis of envisaged performance, is utilized to identify the points in which acoustic vibrations are so high as to produce delamination and cracking of plaster and stone; that means which type of event is suitable to the structure that houses it.



The Figure on top indicates the simulated acoustical level (in false colour), outside and inside the Coliseum, while an example of critical situation is reported below

Some packages with “auralisation” techniques can also reconstruct the sound as a whole, by post-processing the information related to the echograms and to the time of arrival, the power and the angle of origin of the reflections.

The visual environment

The visual predictive programs calculate the spatial distribution of photometric quantities (photometric models) and some of them can also generate a quite realistic display (photo-realistic models). In almost all cases, the programs are a computational tool for artificial lighting, i.e. starting from the photometric characteristics of the devices and the properties of transmission, reflection and transparency of the materials in the environment under consideration; they predict the levels and distribution of illuminance and luminance. The more complex models can extend the calculations to colour and glare with additional packages to calculate natural light. These are however not very common because of poor knowledge of the distribution and dynamics of natural light, in different geographical environments. Only a small number of skies can be simulated by the packages, as generally it is impossible to change the values of the luminance distribution of the sky: not surprisingly the numerical reconstruction can provide natural light levels with considerable discrepancies (even higher than 100%) with respect to the real ones. This situation very often leads very often to the use of standard skies, not real, however that show the advantage of a comparison between different external situations representing a clear day, clouds or intermediate conditions.

The algorithms commonly used in the packages are based on the geometric propagation of light (in its variants of forward ray-tracing, backward ray-tracing and ray-tracing), as in the case of acoustics, or on the radiance concept.

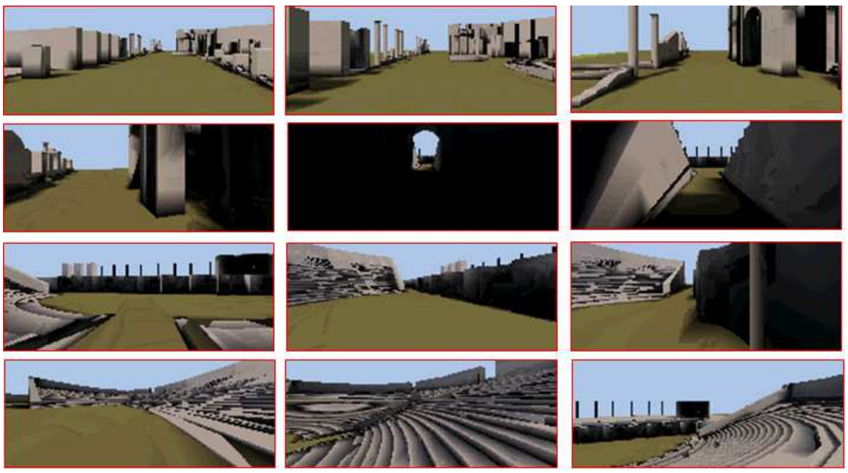
The radiance method, based on the assumption of a perfect diffusing behaviour of surfaces, on the one hand makes the calculations less onerous than the ray-tracing, but on the other hand requires ad hoc corrections when there are specular or semi-diffusive materials, for which the light reflection varies significantly with direction. In operational terms, the actual surfaces are divided by means of grids into small surface elements (mesh) and the calculation is performed on a single mesh and all the others.

The approach based on ray-tracing is usually the best choice in order to generate photorealistic images of phenomena in the presence of specular reflection, while radiance is more reliable in dealing with the dynamics of diffuse reflection, shadow generation and simulation of sources surface (windows, skylights); some of the most advanced calculation models, however, use both approaches. The different numerical simulation codes generate approximation with respect to reality due to the interaction light-environment and to the description of the photometric properties of materials; the visual appearance of surfaces and objects that constitute the environment in the study is solved "following" the path of a finite number of light rays, while the composition of the image on the retina is due to a much larger number of light rays. The photometric properties of materials are usually expressed through the reflectance of light, without specifying its variation as a function of the angle of incidence of light, limiting itself to behaving in a predetermined diffusing or reflecting mode, while almost all the material behaves in a semi-diffusing mode.

Visual predictive programs are useful not only for their design but also because they allow determination of light absorbed rate: excessive values can produce damages.

Below the results of the photometric and photo realistic approach applied to the “Dominae Cubiculm” in Villa del Casale.

Some packages also allow a dynamic representation of the reconstructed scene, allowing you to move the entire model. The Figure below shows some frames for a photorealistic approach and a photometric one (on CIE clear sky conditions at 11 am)



Considerations

The predictive packages are undoubtedly a useful tool for cultural heritage investigations, but their use requires great care as their ease of use and the appeal of generated outputs can be also their weakness; "visually beautiful" is particularly dangerous because it is enhanced in some commercial packages and tend to be structured to always provide an output, even if physically unrealistic and inconsistent. This unreality can be the result of user inexperience, but it can also be hidden in the same package procedures, which may not be sufficiently documented (intentionally or accidentally). The effectiveness of the calculation tool is closely tied to the experience of the user which should not understate the problems and who should have gained some experience in the field to immediately assess the consistency of physical quantities originating from numerical simulations.

Biographical Details

Head of the Department of “Fisica Tecnica”(“Technical Physics”) in the Faculty of Engineering of “ Sapienza” University of Rome until 2010. He produced more than two hundred scientific papers that cover many aspects of applied physics: he worked in natural and artificial illumination (perception basic mechanisms, colour rendering, system and devices), in thermal and visual building simulation (transparent and innovative materials, indoor environment control systems), in applied thermo-fluid dynamics (fire smoke, dust and pollutants diffusion, natural and forced ventilation), in acoustics (noise control and valuation, acoustic indoor quality), in environmental policy and clean technologies (oil spills, nuclear waste disposal, protected area policies, nuclear and industrial sites, cultural heritage).
He developed basic and applied research inside national (CNR, MIUR, ENEA, ASI, ISPESL etc.) and international (IEA,UE, ISES etc.) organizations in which he also covered the position of scientific coordinator.
franco.gugliermetti@uniroma1.it