3D Technology Solves the Mystery of the Great Pyramid

www.3ds.com/khufu

Press Contacts \
Dassault Systèmes EMEA

Virginie BLINDENBERG
Arnaud MALHERBE

Phone /
+ 33 (0) 1 55 49 84 21
+ 33 (0) 1 55 49 87 73

e-mail /
virginie_blindenberg@ds-fr.com
arnaud_malherbe@ds-fr.com

/ Press Contacts
Ketchum for Dassault Systèmes France

Céline ROUHEN
Nawel YOUNSI

\ Phone
+ 33 (0) 1 53 32 56 82
+ 33 (0) 1 53 32 56 21

e-mail /
celine.rouhen@ketchum.fr
nawel.younsi@ketchum.fr

\ Content

Understand and Communicate in 3 Dimensions!

This is the story of an encounter. An encounter of the past and the future. Of history and high technology. Above all, an encounter of men not expecting to embark on such an adventure. One of them was seeking to solve an age-old enigma; the others, glued to their computer screens, were striving to link the future with the present. For their paths to cross there had to be a crossroads. And not just one crossroads in fact but two: the Pyramid of Khufu and 3D technology.

It all began 4,500 years ago, when a civilisation that knew nothing of iron tools, the wheel or pulleys built one of the most mysterious monuments in the entire history of humankind: the Pyramid of Khufu in Egypt. How did they do it? Nobody alive today knows with any certainty. But it was exactly this unresolved riddle that led several teams at Dassault Systèmes, the world leader in real-time 3D technology, to provide backing for an architect and author of a revolutionary theory about the Great Pyramid, Jean-Pierre Houdin.

History has often shown us that scientific theories stem initially from intuition. Jean-Pierre Houdin's hunch changed the course of his life. For the last eight years, he has devoted himself to developing the first scientific theory capable of fully explaining the construction of the Pyramid of Khufu.

Dassault Systèmes' 3D tools are used to design and visualise the finest industrial projects of our age. Many of these projects were unachievable yesterday, and even today they defy reason and breach traditional boundaries. By enabling giant aircrafts, futuristic buildings or even just automobiles, for example, to be designed in record time, industrial 3D tools allow us to think differently and thus innovate. But does the notion of innovation necessarily have to be linked to the future? Couldn't it also help us revisit the past in the light of new ideas? Won over by Jean-Pierre Houdin's passion and stimulated by the challenge, Dassault Systèmes have for the past two years been using advanced scientific 3D tools to examine every detail of his theory.

Because we also think that 3D will be one of the premier mediums of the 21st century, we wanted to share this extraordinary human adventure with the widest possible audience. Thus was born the first virtual reality installation that will allow spectators to travel back in time and visit the amazing construction site of the Pyramid of Khufu in real-time. On the giant screen of the Géode or on a computer screen connected to the World Wide Web, we welcome you on board for this fabulous voyage through time - connecting the future to the past.

Mehdi Tayoubi
Dassault Systèmes

DASSAULT SYSTEMES

See what you mean

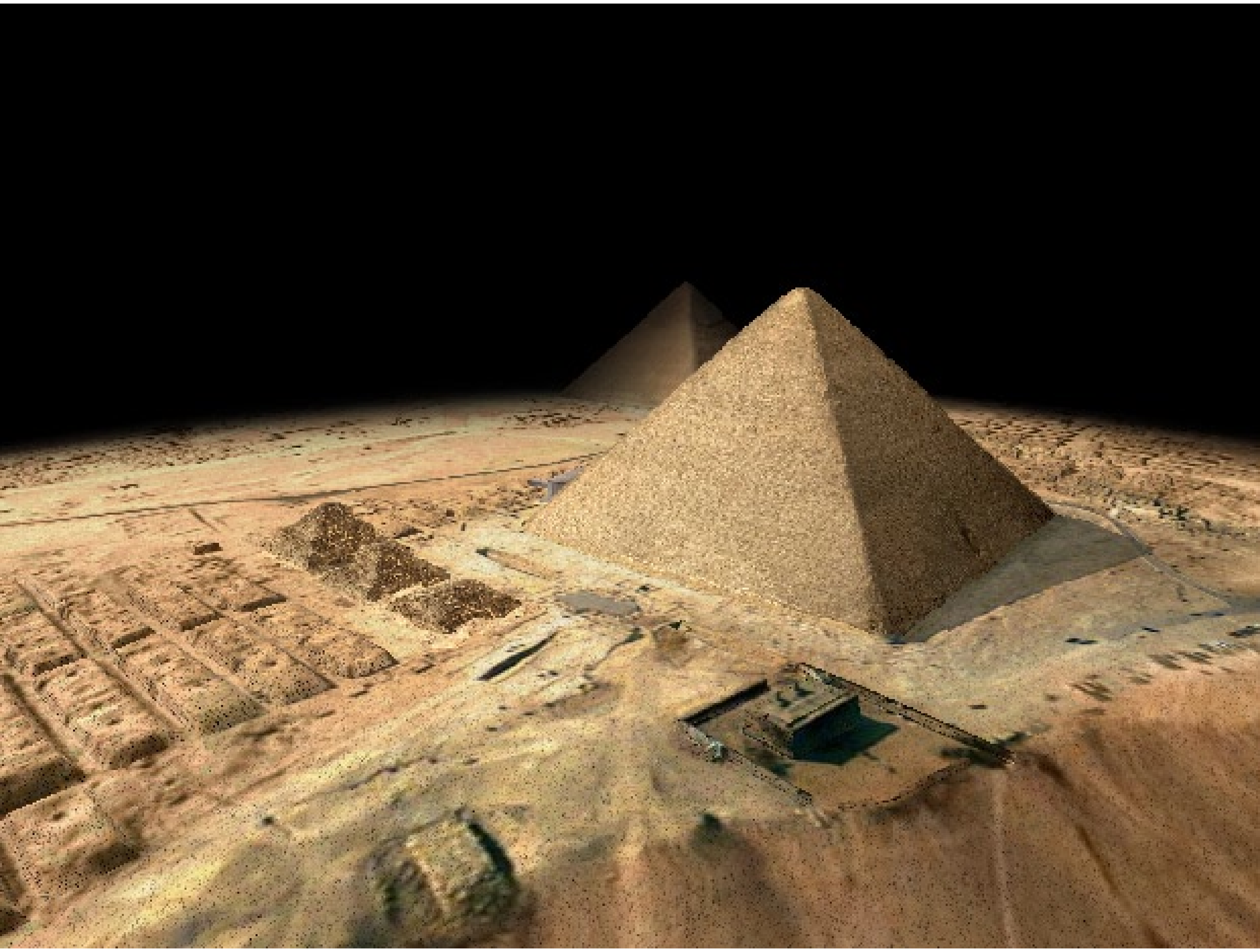
The Last of the Seven Wonders of the World

By definition a pyramid is a solid figure on a rectangular base, having four triangular faces meeting at an apex. For historians, it is a royal tomb from ancient Egypt. For the whole of humankind, the three pyramids standing on the Giza plateau at the gates of Cairo, Egypt, Khufu, Chephren and Mykerinos, represent both a treasure and mystery.

What we know about these pyramids is that they were built nearly three thousand years before Christ to contain the remains of three pharaohs. Although the most impressive of these stone structures, the Pyramid of Khufu, has been studied and photographed countless times, its heart remains a mystery, evoking images of incredible riches and powerful curses.

The Great Pyramid is said to be the last of the Seven Wonders of the World still standing, the only one to have resisted the madness of men and the fury of the elements through time. It was known as the tallest structure in History with a height of 146 metres, until the Eiffel Tower was built. And yet we know neither how it was built nor how long it took to build, by men who had no knowledge of iron tools, wheels or pulleys. We have no idea what astonishing finds still lie concealed behind its stone walls.

As a witness to 4,500 years of history, the Pyramid of Khufu has seen the world's greatest men come and go. Men who admired the excessiveness of its symbolism, who dreamt of infinite conquests or even of immortality. Passing rulers and anonymous travellers, over the centuries so many have come to walk on its stones. Some, intoxicated by the extraordinary feeling of the place, told themselves that such excess could have no human origin and that only an alien civilisation from far away could have produced such a marvel.



The Great Pyramid : Myth and Reality

Over time, the secret of the construction of the Pyramid of Khufu has been lost. Men have thus been free to let their imaginations run wild, creating theories that range from the impossible to the far-fetched. Real clues are sparse, for example a few lines about the royal architect Hemiunu, who is supposed to have built the pyramid in just twenty years so that the great Khufu could be laid to rest in the heart of his vessel of limestone and granite, a container for the eternal life of the King.

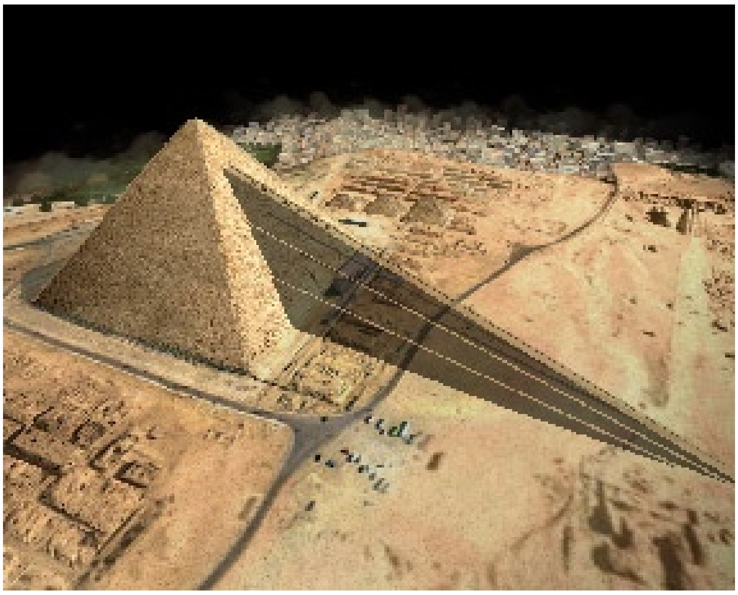
There are also a few sentences from Herodotus, providing another clue perhaps: the famous Greek historian travelled to Egypt around 450 BC, more than 2,000 years after the pyramid was built, and wrote down local legends. In his book, Herodotus describes a tyrannical King with thousands of slaves dragging stones. Curiously, he says that machines were placed beside the structure to lift the stones from one level to the next. Four centuries later, another Greek historian spoke of a vast frontal ramp used to haul the blocks to the summit. Others talked of an external helicoid ramp made of unfired bricks, but this idea fails to stand up to serious analysis.

The large ramp hypothesis. Large ramps require a volume of stones almost equal to that used in the pyramid itself. In addition, the work of the site would have to be interrupted continually whenever the ramp was extended. Such ramps would be either short while too steep to be useful, or shallow yet several kilometres long. Furthermore what became of the material used in the ramp? It seems irrational to build the entire pyramid with a large frontal ramp.

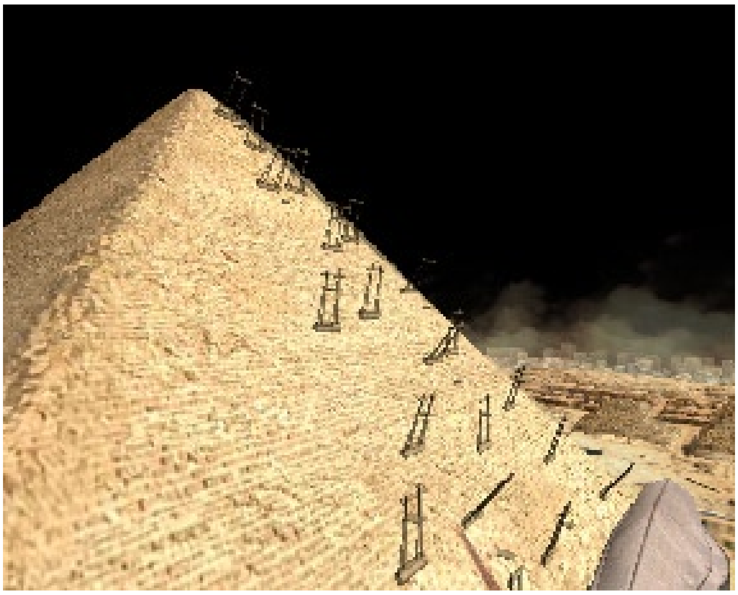
The machine hypothesis. This is the hypothesis reported by Herodotus: machines were used to lift the blocks from one course to another. One theory also describes the use of levers and wedges to lift each block ten centimetres or so with each heave. But how could blocks weighing 65 tonnes have been raised in this way? Could workmen act as counterweights to lift the blocks which would then be dragged into position? A slow and dangerous operation in any case, it simply would not have worked for larger blocks. Moreover, such machines would need a flat support. Thus the whole structure would have undergone a rough-cast finish after the work... The time constraints are too short for this! Machines of this kind were perhaps used, but they could not have been key to the construction method.

The spiral ramp. This is the most popular hypothesis today. An external spiral ramp was constructed around the pyramid. The advantages to this method are that:
• it could help build the pyramid with unfired bricks, using a relatively small amount of material;
• progressive construction would follow the progress of the site without slowing it up too much;
• an external ramp would provide a constant shallow slope of 8%. Even so, in practice, it could not work, as it would have been impossible to check the geometry of the pyramid if it were hidden by the ramp. Furthermore, such a ramp would be fragile and would collapse regularly. Turning the corners would be risky and the pathway would be too narrow.

Considering the above, it was far time to find a rational solution to the mystery of the Pyramid of Khufu; a solution that would enable us to explain its construction from start to finish and that would answer all the questions asked over so many years.



The large ramp thesis



The machine thesis

The spiral ramp

By Jean-Pierre Houdin

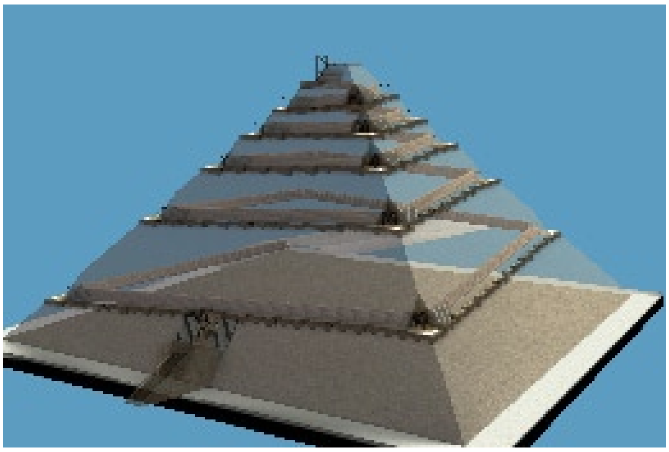
The Man Behind the Theory

I was born in Paris in 1951, but I grew up in Abidjan, in Africa, where my father was the director of a construction company. As a small boy, I spent my spare time on construction sites while my mother, who was a doctor, cared for her patients in a bush dispensary. My interest in building and construction no doubt grew out of this first period of my life. Back in Paris, after the baccalauréat, I naturally enrolled in the Ecole des Beaux-Arts, in the architecture section.

After obtaining my diploma in 1976, I set up as an independent architect, a profession that I would follow for twenty years. I participated in the construction of a large number of residential and office buildings in and around Paris. At the same time, with my wife Michelle and our friend Laurent, I opened an avant-garde art gallery cum salon ("Les Enfants Gâtés"), which over a period of ten years supported scores of young artists, and which became a centre for the arts in Paris at the turn of the 1980s and 1990s.

In 1996, Michelle convinced me to move on and we decided to take a year out in New York! I went with no specific plans but with a thousand ideas in mind: I was eager to start learning again and excited to be able to work in freedom, without constraints. It was the perfect moment for such an approach, because the 1990s saw the remarkable development of the Internet. This new communications medium presented a universe of new perspectives for every field of activity, including for my work. I learned how to use the Internet and how to use the first digital design tools. I got involved in website design, first in New York then in France when I returned to Paris in 1998, with a new career and a whole world of new experience. On January 2, 1999, while I was once again away in New York, my father, a retired engineer, saw a television programme about the construction of the pyramids presented by François de Closets. With his civil engineer's eye he took a critical look at theories in vogue at that time. He thought they just didn't stand to logic. And then suddenly an idea dawned: what if the pyramids had been built from within – from the inside out as it were? This was a revolutionary concept that swept away all the other hypotheses that had been put forward until then. As an architect with experience in three-dimensional graphics, I was called in to assist him in his research.

Suddenly an idea dawned...
What if the pyramid had been built from the inside out?



During 2000, we met with members of the team who, in 1986, had worked on the mystery of the Pyramid of Khufu under the aegis of the Fondation EDF. They showed us plans on which we discovered a construction anomaly, a detail in the drawings that none of the hypotheses could account for. This anomaly, baptised "the spiral structure", looked exactly like a ramp built inside the pyramid which could have played a part in its construction!

In 2003, my father created the Association of the Construction of the Great Pyramid (ACGP) in order to promote the project. This association enabled me to meet a number of experts. In 2005, Dassault Systèmes welcomed me enthusiastically into its brand new sponsorship programme "Passion For Innovation". Together, we decided to examine the theory in the light of Dassault Systèmes' industrial and scientific 3D

« This revolutionary idea sweeps away all the other hypotheses put forward up to now. »

solutions. I would finally be able to analyse and confirm my theory in the virtual 3D world, which enables today's industrial corporations to produce in the real world.

Using these software applications to reconstitute the site of this gigantic construction in three dimensions allowed us to test in real-time whether such an approach was plausible. We would see whether the human and material organisation that it implied was optimal and coherent and whether it conformed to the unchanging laws of physics and mechanics. Hundreds of calculations and algorithms were used to gauge the soundness of our premise, to check whether our models and hypotheses defied the laws of gravity or operated contrary to the forces and the materials being manipulated. Simulations were used to back up and enrich the theory, continually inciting me to ask new questions to ensure that no doubt would remain concerning the mystery of the construction of the Great Pyramid.

But it was not enough just to confirm the theory. We had to explain it and communicate it: we had to share the secret of the construction of the sole survivor of the Seven Wonders of the World with the public. With Dassault Systèmes, we decided to push the challenge even further by using 3D technology as a teaching medium and to propose the first interactive voyage through time in three dimensions, both on the giant screen of the Géode and on the Internet at www.3ds.com/khufu. This would be a world premiere and proceed the field-based scientific exploration that would enable us to probe the actual pyramid in order to find proof to confirm the existence of the internal ramp.

The contribution of scientific 3D technologies. Jean-Pierre Houdin explains the history of the cracks in the King's Chamber, which we were able to reproduce precisely through FEA simulation.

The theory being presented by its inventor. Jean-Pierre Houdin elucidates, wearing 3D glasses.

The "Passion for Innovation" Programme

Dassault Systèmes and Jean-Pierre Houdin

To innovate, is to strike out from the beaten track, to question concepts that sometimes seem unchangeable. Innovation is what stirs the most passionate and courageous men to suggest new ideas, to seek fresh ways of seeing things. But innovation is also about having the right intuition, and knowing enough about one's own field to be able to rethink certain aspects of it, with the help of the right tools. These tools can then be used to develop and confirm new hypotheses. All the theories put forward about the pyramid up to the present have been based on the premise of external construction. But what if the Great Pyramid of Khufu had been built partly from the inside out?

A shared passion for innovation. On the basis of this revolutionary hypothesis, Jean-Pierre Houdin decided to tackle one of the oldest mysteries in history by entirely rethinking the construction of the Pyramid of Khufu and by proposing a startling new theory. He set out to overturn traditional theories with the help of real-time 3D technology, which he would use to investigate one of the most famous architectural sites in the world. Jean-Pierre Houdin worked on this project for six years, convinced that the pyramid should be seen as the first great industrial site in history, managed by true engineers, albeit in the very distant past. He imagined every stage of construction, step by step. When the meeting with Dassault Systèmes took place, the theoretical and rational model was already in place and the field evidence had been painstakingly sifted.

The aim of the Dassault Systèmes "Passion for Innovation" sponsorship programme is to contribute to the fulfilment of innovative not-for-profit projects by providing support through the loan of

The 21st century Time Machine

Dassault Systèmes' 3D and training software, along with the provision of a specific skills base. Jean-Pierre Houdin and the Dassault Systèmes teams led by Mehdi Tayoubi decided to take up a dual challenge:

1-
To use industrial and scientific 3D tools to confirm the theory. After all, if these software applications can be used by Dassault Systèmes' customers (Boeing, Toyota, Nokia etc.) to design and simulate both the products and processes of an industrial programme in a virtual 3D environment before starting production, it ought to be fully possible to rebuild the entire pyramid, taking all the aspects of construction into account (manpower, materials, processes, historical constraints etc.).

-

Dassault Systèmes industrial and scientific 3D tools are used to confirm Jean-Pierre Houdin's theory.

2-

To use real-time 3D as a teaching medium to communicate and explain the theory. To allow web users all over the world to visit and experience the site freely in real-time and in 3D exactly as it was 4,500 years ago and follow all the stages of construction. To transform the Géode into the greatest centre of 3D virtual reality in the world with a unique three dimensional experience controlled in real-time by seven networked computers.

A multidisciplinary team of some fifteen people (engineers, designers, developers etc.) worked with M. Houdin for nearly two years. Again and again their shared passion pushed back the limits of the study. While the pyramid was rebuilt level by level in a virtual environment, confirming the hypotheses of the theory, 3D technology enabled the team to "see" afresh, leading them to pose new problems and, inevitably, to undertake new simulations. Thus the theory was refined and confirmed, entirely in a virtual environment, in a true anti-chamber of reality. From the external ramp used to build the lower courses, to the internal spiral ramp running behind the faces of the pyramid and from the system of counterweights to lift the beams of the King's Chamber, to the historical reproduction of the cracking of these beams, all aspects of the site were simulated! This work of modelling, calculation and simulation in 3D confirmed for the entire team the respect that they felt for the people who had raised this building 146 metres high, 45 centuries ago, without wheels and pulleys.

Fifteen enthusiasts from different horizons joined the quest as it moved forward. David Nahon, Dassault Systèmes Manager for Virtual Reality Products and Solutions and Fabien Barati, a Virtools specialist.

Olivier Begin Manager of the Simulation Works department and Jacques Jaworski, consultant in Product Life-cycle Management (PLM) in front of a process simulation.

Allowing the Public to “Walk” Freely Through the Pyramid Site in Real-time 3D

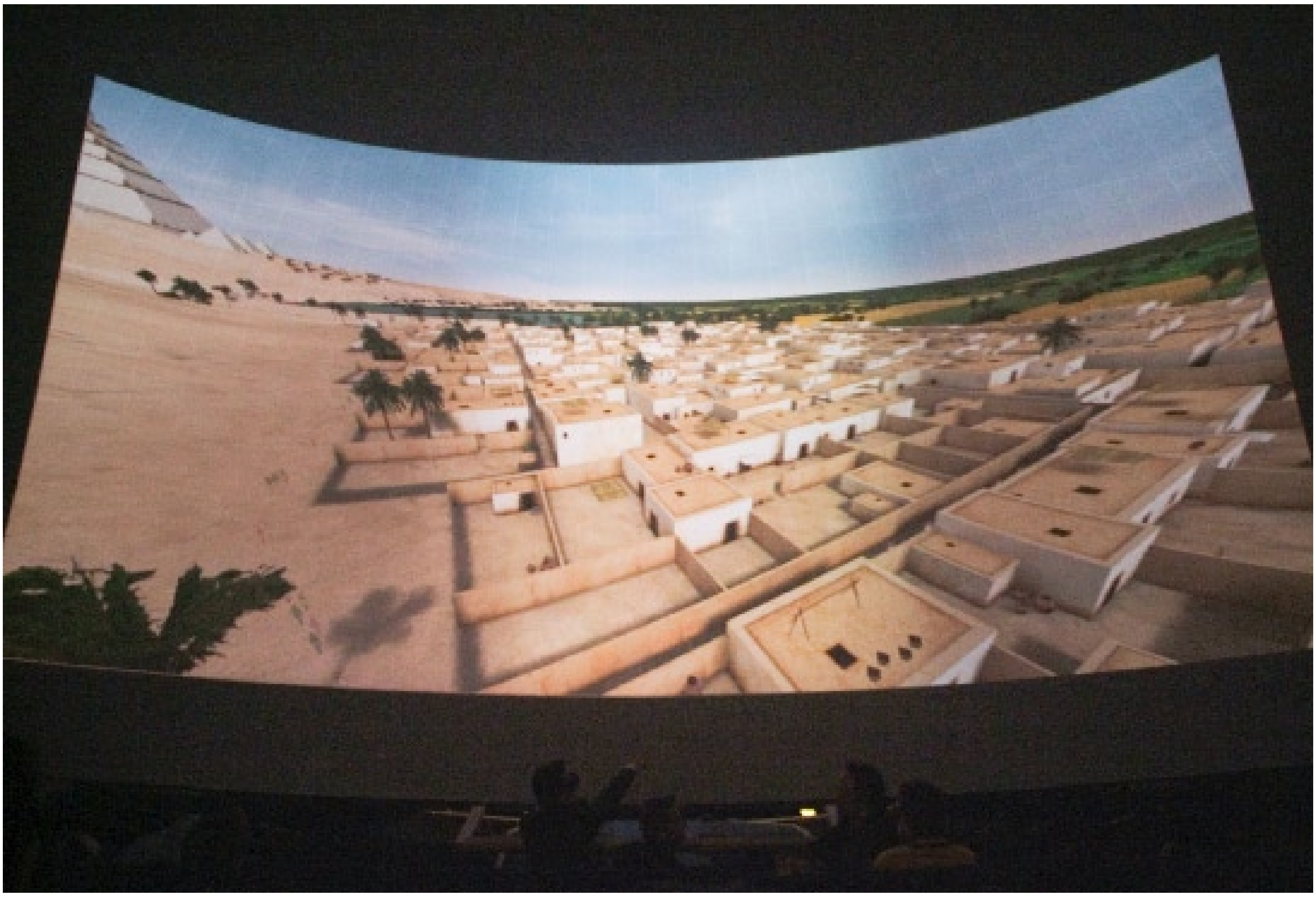
The Géode transformed into a virtual reality lab for the first tests. Left to right: David Nahon, Fabien Barati, Emmanuel Guerriero, Geoffrey Subileau, Sébastien Kuntz.

Once the task of verification was completed, the second phase of the project was to enable this extraordinary adventure to be shared in three dimensions with the general public, both over the Internet and by offering an unprecedented experience at the Géode. Wearing 3D glasses, the “time travellers” would plunge into an interactive stereoscopic adventure on the Giza plateau as it was 4,500 years ago. Moving freely through the site, they would follow Jean-Pierre Houdin as he took them for the first time into the corridors situated deep within the pyramid!

Intuition, hypotheses and verification. Like any scientific adventure, this one started with an intuition, followed by a long stage of hypotheses and verification. Now for the first time the evidence was clear. The 3D application used to follow all the processes described showed that the pyramid could be constructed in twenty years or so.

A certain number of indications already existed, such as the 1986 EDF microgravimetry readings. Demonstrating differences of density, these microgravimetry readings indicated that cavities existed within the pyramid…

The final proof. Now all that remained was for Jean-Pierre Houdin to visit the actual site as part of an official field-based scientific mission. This mission was supported by, among other experts, Rainer Stadelman, ex-Director of the German Institute of Archaeology in Cairo, a specialist in the pyramids, Bob Brier, Egyptologist, professor of philosophy and a world renowned expert in the field of mummies, and Marc Buonomo, project leader of the innovative and impressive Millau Viaduct. Their aim would be to sound out the pyramid and obtain the definitive evidence required to solve the mystery of the construction of the Pyramid of Khufu.



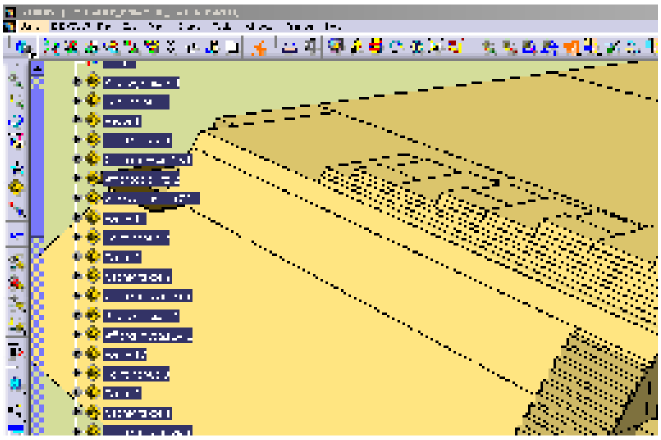
The first interactive 3D time machine is up and running.
We are ready to share with you in 3D all the excitement of this awe-inspiring construction project.

How Scientific 3D Technology Contributed to the Theory

Jean-Pierre Houdin's theory is the first to have been confirmed by means of high-performance 3D modelling and simulation software. It is also the first theory to explain the construction of the Great Pyramid from start to finish and to supply answers to all the major questions. If an identical pyramid had to be built today with the materials and constraints of the time, the work would take around twenty years. No other theory had endorsed this until now.

Dassault Systèmes gave Jean-Pierre Houdin access to all their solutions. This technology is normally used in industrial product creation and manufacturing to design and manage different products, from simple mineral water bottles to very complex systems such as aircraft, automobiles or the spectacular buildings designed by architect Frank Gehry. 3D simulation is also used to check the operation of production lines (organisation, task sequencing, work-place ergonomics, relations between production centres etc.).

Today, three-dimensional design and simulation enable industrialists to obtain results rapidly and economically, by working on virtual doubles of their products or their plants. Real-time 3D allows designers to be bolder and more creative and get products right from the start by anticipating the entire life-cycle of a product before actual production. If we consider that the construction of the Great Pyramid was an industrial site ahead of its time, it would seem natural to apply the same methods and tools to it. We therefore modelled the Great Pyramid in 3D and subjected the construction processes developed in Jean-Pierre Houdin's theory to scientific simulation.



3D modelling of the pyramid in CATIA, 3D design software.

06a_ Scientific 3D Simulation at the Service of the Theory

The First Complete Theory of the Construction of the Great Pyramid Subjected to Scientific & Industrial 3D Simulation

The theory in 3 points

1_

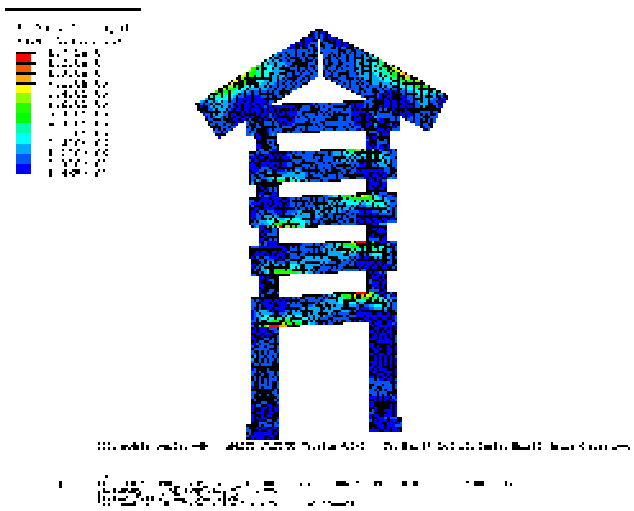
Up to the 43 m level an external ramp with two separate carriageways was used to supply massive amounts of huge stone blocks representing 73% of the pyramid's total volume. Constructed from the beginning to their maximum length (about 400 m) with an 8% slope, the carriageways were used alternately for block haulage up to the course under construction, the unused carriageway being raised by two courses to enable the construction of the next course. In this way, construction was never interrupted to raise the ramp in line with building progress.

2_

An internal spiral ramp with a shallow 7% slope ran inside the 'skin' of the pyramid to allow completion of the pyramid above the 43 m level. Although this ramp was constructed from the outset, from the base of the pyramid, it was not used during the first years of construction. From the 43 m level onwards, materials were supplied from the external ramp, which was progressively dismantled, its blocks being recut to provide stones weighing approximately 2 tonnes, then hauled up this internal ramp. At the end of each flight, recessed landings open to the sky enabled the blocks to be rotated through 90° by means of wooden jibs which also positioned the blocks for haulage up the following flight. At the end of construction, these recesses were progressively filled in by stones kept in reserve on the sidewall close to the recesses. This work proceeded from the summit and descended to the base of the edifice.

3_

The use of the Great Gallery as a 'site crane', allowing a counterweight carriage ballasted with stones to travel on a bed of wooden rollers. The counterweight provided the motive force to lift the huge blocks of granite that form the five ceilings of the King's Chamber up to level 60 m. Some of these blocks weigh nearly 63 tonnes.

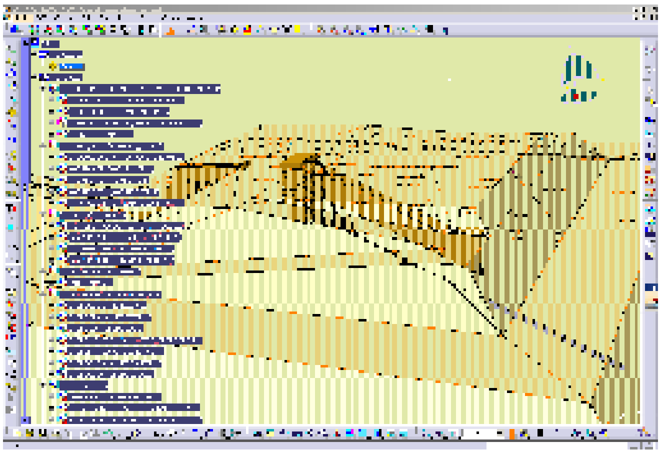


Analysis of the King's Chamber in SIMULIA. This software is normally used by industrial corporations to simulate the behaviour of their products in operation and to detect any structural weaknesses in order to solve problems as early as the design phase. Here, the software was used to explain the history of the cracks in the King's Chamber, which we were able to retrace precisely thanks to scientific FEM simulation.

Using 3D Technology to Confirm the Theory

Modelling /

The vital first stage.
Modelling takes place in three stages. The aim is to obtain a virtual double of the pyramid which will behave identically to the real pyramid with regard to the laws of physics



3D modelling of the pyramid. The pyramid is drawn with its exact measurements in three dimensions in CATIA. The entire monument, with its complete internal layout of corridors and funeral chambers is clearly visible. The 3D model can be manipulated and observed from all angles. Transparency effects can be used to examine the virtual edifice in ways that would never be possible in the real pyramid. The 3D model also allows the distance between any two points to be measured instantaneously in space, enabling multiple hypotheses to be tested quickly. Only the most promising are retained. Only 3D modelling allows this work to be performed so rapidly and easily, even on a simple laptop computer!

_1
Geometrical modelling
consists in recreating the pyramid precisely in 3 dimensions, with all its available measurements and with the complete layout of its interior corridors and funeral chambers. The geometrical model can then be manipulated at will: it can be turned in any direction and examined from any angle, cross-sections can be defined, the layout of the internal corridors and the funeral chambers can be visualised transparently etc. Such manipulations of the 3D model, which are utterly impossible on the real pyramid, allow a vast range of observations to be carried out very rapidly. The 3D model in particular enabled Jean-Pierre Houdin to acquire a deeper understanding of the monument and to establish relations between certain measurements (the distance between any two points on the model can be obtained instantaneously). The ability to compare certain gradients with the length of the different internal structures of the pyramid provided the architect with both insights and evidence for the development of his theory.

_2
Physical modelling
As the geometrical model cannot be used to simulate events, physical modelling is used to enrich the geometry with the physical characteristics of the materials used in the pyramid. Using Dassault Systèmes' software integrating physical laws, it was possible to simulate the behaviour of the virtual pyramid as if it were the real thing, for example the resistance of the materials or the effect of the weight of the pyramid on itself etc. It's easy to identify the location of limestone or granite elements, but also to get their physical parameters (density, elasticity etc.). This data is then integrated to the geometrical model which thus increasingly resembles the real thing.

_3
Functional modelling
The Jean-Pierre Houdin's theory integrates a certain number of mechanical systems such as sleds or carriages running on wooden roller beds. The characteristics and disparities of such systems are well known in mechanics (e.g. the friction generated by a skid sliding on a rail is not the same as that of a load being moved on a roller). These characteristics are integrated into the 3D model in order to obtain a total model with the same dimensions, and the same physical and functional parameters, as the real pyramid.

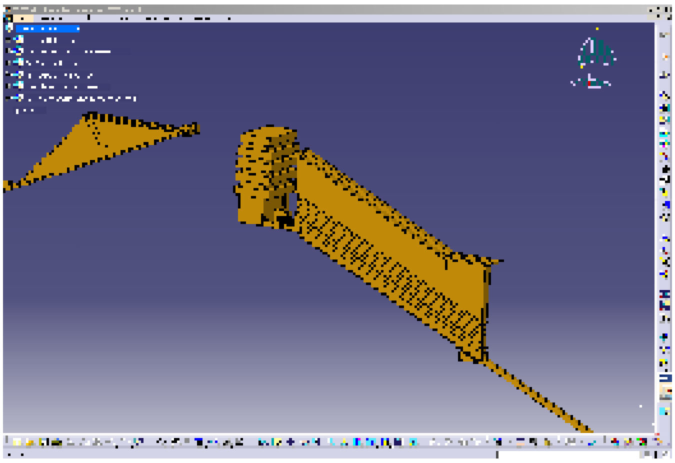
Any scientific approach comprises three stages: intuition leading to theory, followed by demonstration and experimental proof..

Simulation /

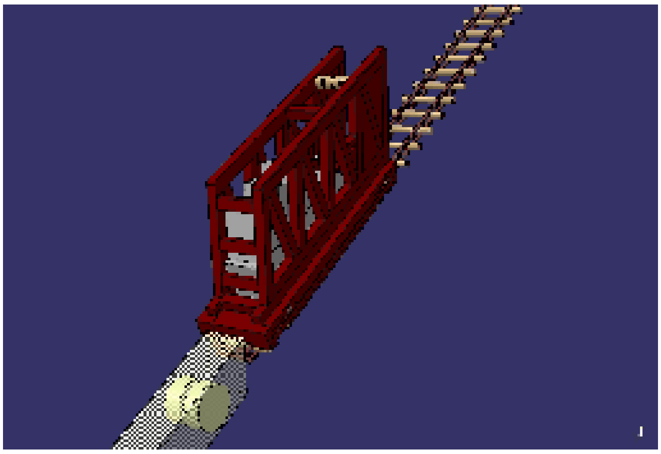
Once the 3D model had been completed, the full range of Dassault Systèmes software solutions were used to simulate the construction processes suggested by Jean-Pierre Houdin's theory and check their validity and coherence. These software applications are normally used by industrialists to simulate every aspect of the production process, from plant design to the operation of the production chain (location and programming of robots, verification of work station ergonomics by means of virtual dummies, etc.). These tools were then applied to the hypothesis advanced by Jean-Pierre Houdin.

They revealed no incoherence or impossibility in the theory. Better still, the complete simulation of the construction processes validated the theory by allowing the duration of the building work to be estimated at around twenty years (the length of the reign of Khufu).

A critical aspect of the Dassault Systèmes software used is that it takes into account the vitally important parameter of time. Today, manufacturers are desperate to shorten what is known as 'the cycle time'. Products must be designed and produced more and



3D modelling of the great gallery and of the King's Chamber. The 3D model allows certain elements to be masked so that attention can be focussed on the essentials. This facility offers real comfort for the study of certain specific points.



Scientific validation of the system of counterweights: the operation of the system is thoroughly checked in CATIA, with special attention to the relative movement of the different components.

more quickly in order to get products to the market before the competition. Dassault Systèmes software facilitates the optimisation of tasks at all levels by integrating this vital time factor.

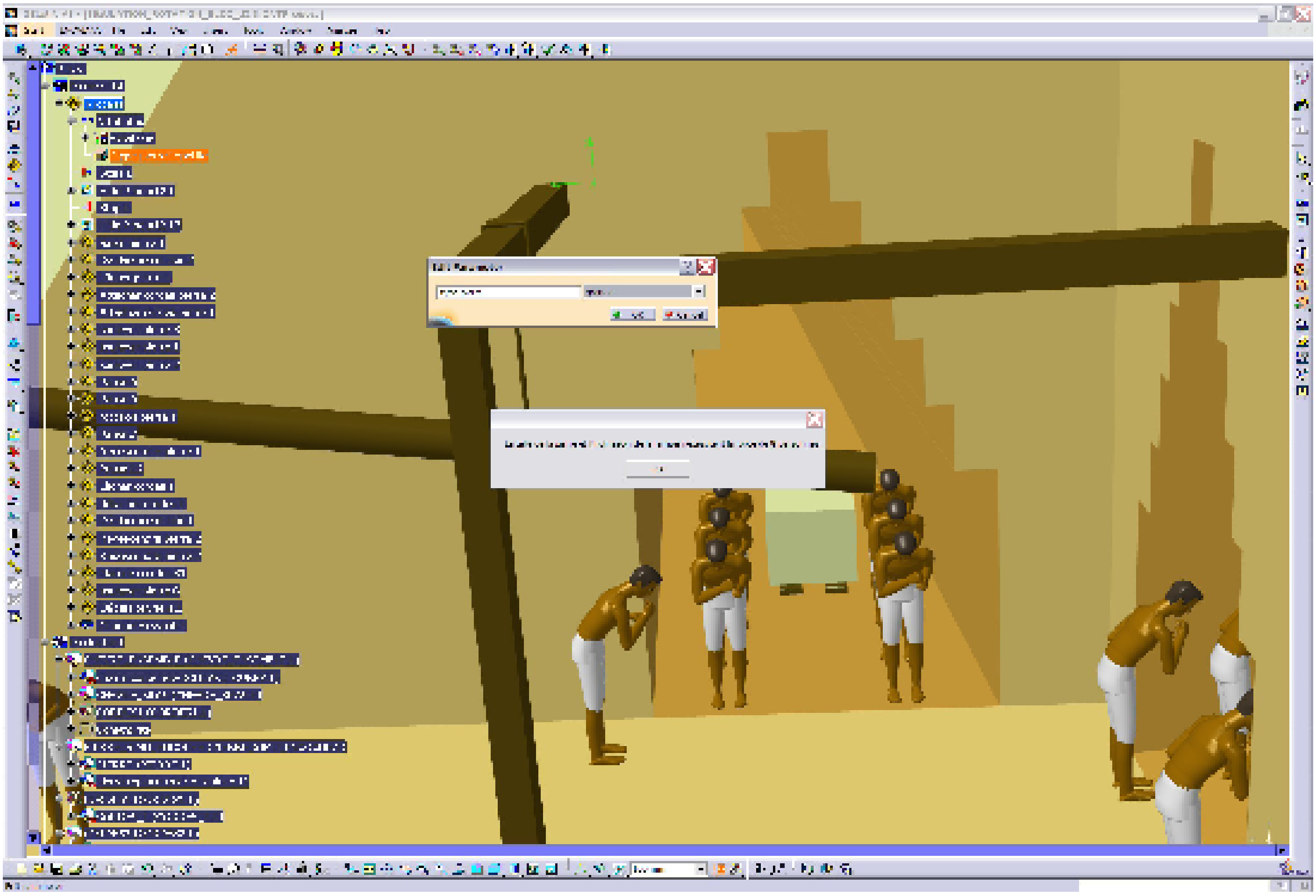
From the virtual to the real. Without replacing field-developed observations, analysis of the 3D model and simulation of its behaviour can be used to prepare observation missions more effectively.

Any scientific approach always comprises three stages, always in the same order :

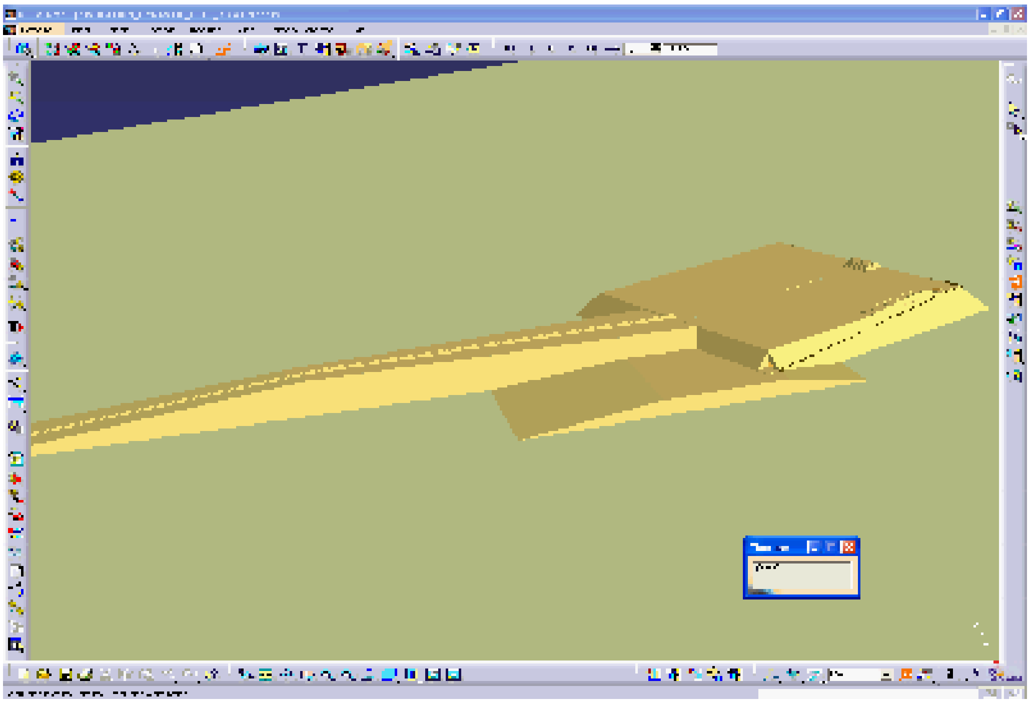
- Intuition, leading to the development of theory 'the pyramid was constructed from the inside',
- Painstaking demonstration of the theory
- Experimental proof

3D modelling and simulation had provided the demonstration, now it was time to test the theory on the ground and verify the presence of the internal ramp experimentally. At this stage, the 3D model would still be useful in helping in the positioning of detection and measurement devices in order to obtain a result in the best conditions without damaging the monument.

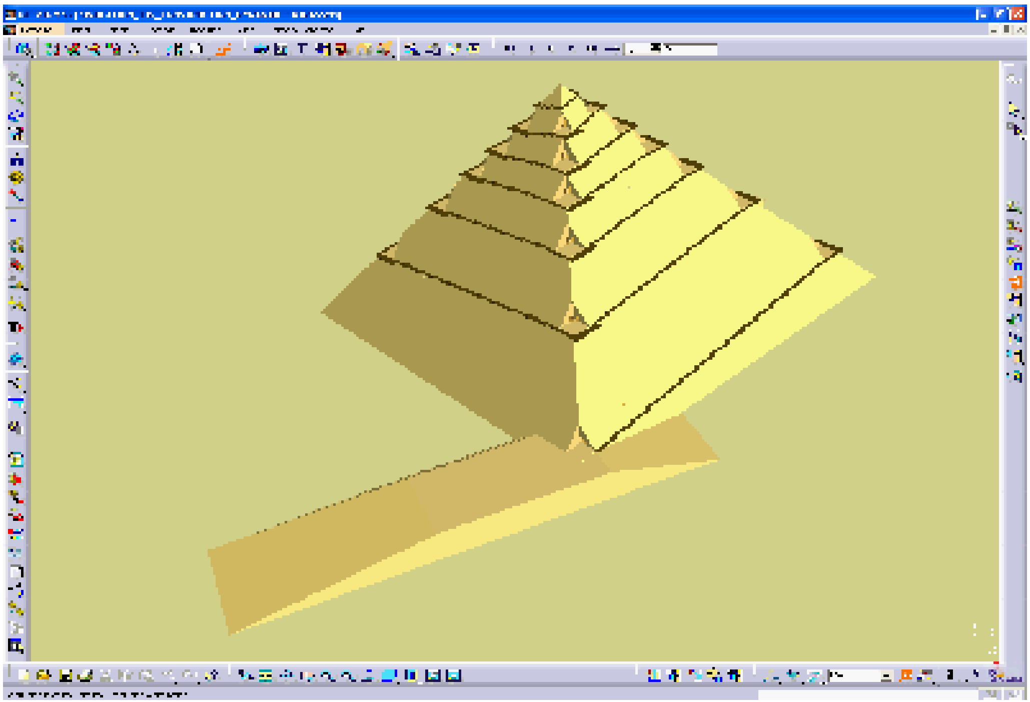
3D Technology in Images



Scientific validation with DELMIA of the block rotation system on the recessed platforms. DELMIA solutions are used in industry to design and validate production processes. DELMIA integrates both mechanical and human factors. The characters shown above are 'virtual humans' whose physical limits are known (maximum pulling power and endurance). The software is used to check not only that the system works (mechanical aspect) but also that the number of workers required is compatible with the space available on the platform (human aspect). Finally, DELMIA integrates the time factor, enabling the rotation time for a block to be quantified at around one minute.



Integral simulation of the construction process in DELMIA: this software is also used to simulate the main stages of construction and visualise the logical sequencing of these stages by taking the time factor into account. This is the ninth year of the reign and the external ramp is providing a massive supply of stones of the right size to the site.

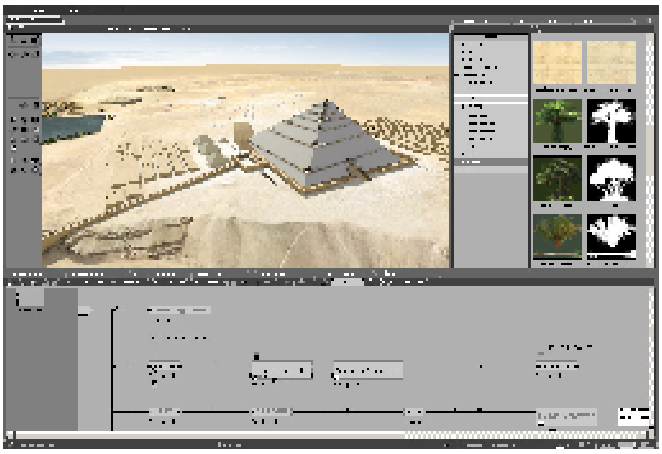


The site in the twentieth year of the reign: DELMIA has allowed us to follow from start to finish the exact progress of the construction process suggested by the theory of Jean-Pierre Houdin.

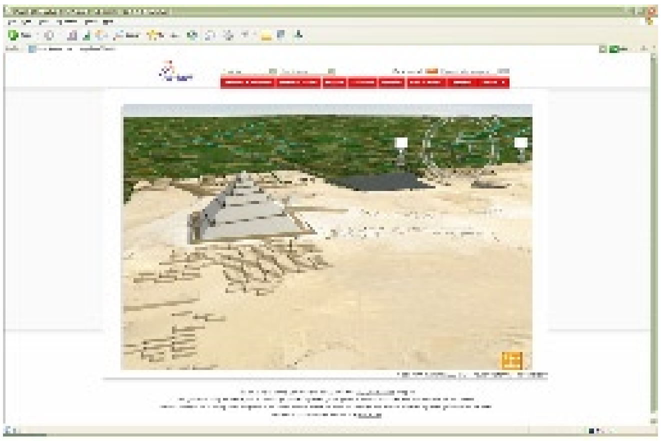
Real-time 3D For All

The future of communications in general, and especially on the Internet, is in 3D. With communities sharing and exchanging files in 3D, the provision of services offering three dimensional colour-printing, product design and customisation on-line and on demand or consumers' avatars trying on clothing or accessories ... Real-time 3D offers a total interactive experience which stimulates enormous interest. Users take in and apply concepts more easily than with any other media. Any interactive web content gains power when it gains a dimension. Just after the new generation Web 2.0 was announced, for example, Web 3D was already on the horizon. With its multi-platform Virtools 3D technology, Dassault Systèmes intends to play a major role in putting 3D within the reach of the greatest number by developing interactive applications on the Internet. The Khufu project and the **www.3ds.com/khufu** site are illustrations of the possibilities offered by real- time 3D.

Virtools technology. In many ways, Virtools is to 3D what Flash is to 2D. It facilitates content editing and manipulation and simplifies interactivity management. Virtools is a solution which brings 3D to life. Virtools can, for example, be used with the same content to create a real-time 3D experience online or in a virtual reality installation. If services such as Second Life have shown advertisers how to capitalise on the opportunties



A single tool to create a multi-platform interactive 3D experience



On the web at **www.3ds.com/khufu**

presented by 3D and Web communities,
Virtools opens up an entire world of 3D experiences that are truly life-changing and whose only limits are those of the imagination.

Dassault Systèmes and Geode have joined forces to create the largest real time 3D virtual reality installation in the world. Implementing Dassault Systèmes Virtools solutions, seven computers linked to a network are harnessed to reconstitute the Khufu site in 3 dimensions exactly as it was 4,500 years ago and to allow free movement inside the pyramid in response to questions asked by the public.

Using mass media virtual reality techniques

The key medium of the 21st century : web 3D and giant interactive emotion

So, after the inauguration of 'Geode Films 3D', 'Geode HD' and 'Geode Live', Dassault Systèmes and Geode now present 'Geode Virtual Reality', the largest real-time 3D virtual reality auditorium in the world.

This is a world premiere which prefigures future installations and events, combining the real and virtual worlds thanks to a total 3D experience. The only limit to this unique installation is the imagination of the artist who can, thanks to Virtools, cast his creation on the Web as well as on giant screens like that of the spectacular Geode theatre (an image 25 m wide and a total projection area of 400 m2!).

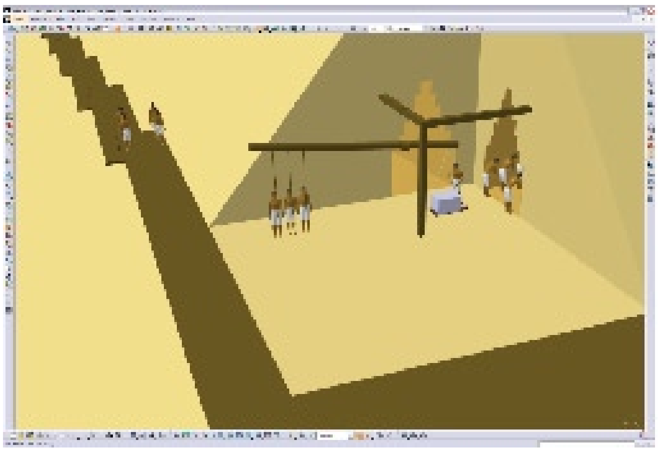
Test screening at the Geode (DS transforms the Geode into the largest virtual reality auditorium in the world) where the content is controlled in real-time by a '3DJ'. In response to questions from the house, the audience moves around the construction site of the pyramid like the first tourists on a trip through time.

Dassault Systèmes and Geode are providing access for the general public to discover this experience in the fabulous Geode auditorium (a 26 m diameter dome with a seating area of 1,000 m2).

The 3D revolution is under way...

Innovation and Creativity in 3D

Real-time 3D technologies, are revolutionising the way we see the world we live in just as the invention of perspective did in the 15th century. In the realm of science, in communications and data sharing and, especially, in interactive applications, 3D is fast becoming the key tool and medium of the 21st century. By modifying our perception of the world and by providing extraordinary interactive experiences, 3D is par *excellence* a technology at the service of innovation. It has already transformed the worlds of video games, cartoon cinema and industrial production. Now 3D is breaking out of its circle of initiates to revolutionise an ever-increasing number of human activities. Jean-Pierre Houdin's theory is a true innovation born of real-time 3D technology. And, thanks to that technology, the theory has also been revealed, communicated and explained to the general public.



Real time 3D as a scientific tool in the service of innovation.

A strategy of Innovation

_1
No innovation without intuition !

Because it facilitates changes of viewpoint and because it enables concepts to be manipulated and played with at will, 3D allows us to see things differently and stimulates new thinking. For example, the intuition of the cause of the sinking of the South wall came to Jean-Pierre Houdin because he was able to watch the cracks in the King's Chamber appear thanks to software used to simulate crash tests. In addition, many details of the theory were refined by visiting the construction site in real-time 3D wearing virtual reality hard hats. The experience and emotion of the virtual world was used to sharpen all the details of the site so that it could be made as realistic and as plausible as possible.

_2
The right tool

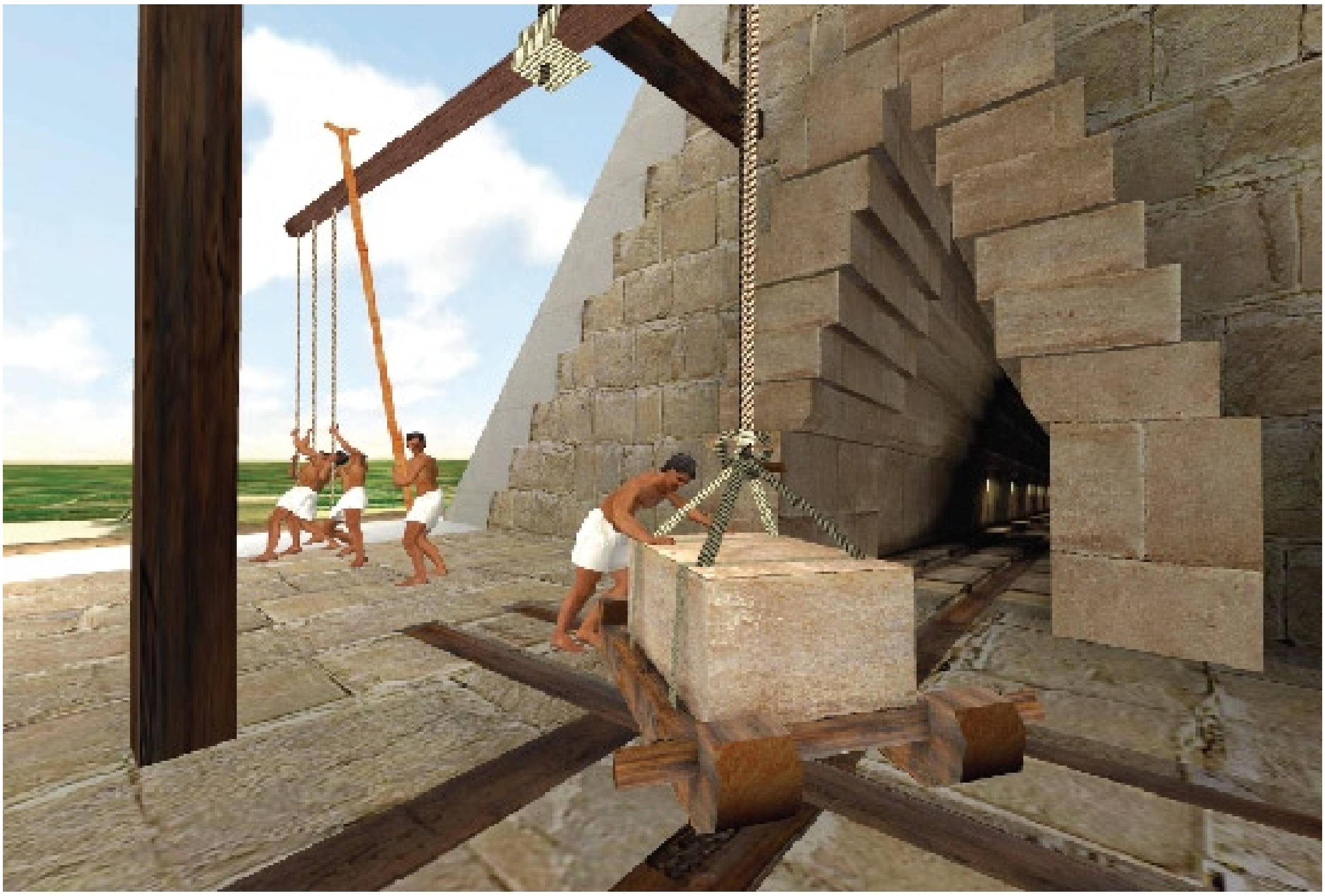
Innovation also means being able to confirm hypotheses, perform tests and venture down paths which sometimes prove to be without issue, before finding the right solution. The 3D tools used in industrial applications enable the premises of a problem to be changed in real-time and the result to be visualised instantaneously on screen. Jean-Pierre Houdin's theory and its various hypotheses were analysed and simulated in 3D until the entire pyramid had been built in a virtual environment.

-

The vocation of Dassault Systèmes is to foster innovation and creativity as widely as possible thanks to real-time 3D.

3_ Learning and sharing

Innovation also means being able to communicate effectively to allow the widest possible audience to recognise, appreciate and make use of an invention. 3D, as a truly universal visual language, allows concepts that are in principle complex to be understood easily. Interactive 3D applications already provide outstanding training tools in multiple industries (for example, training in aeronautics maintenance routines). When we add a virtual dimension which allows the user to be totally immersed in a sensorial universe, into a reproduction of the real, the emotion aroused makes the experience of real-time 3D much more powerful. Interactive game-based educational applications that were developed only yesterday in two dimensions using technologies like Flash gain an additional facet to offer a new learning experience both for the general public and for specialists. Dassault Systèmes illustrates this perfectly by offering the opportunity to visit the plateau of Giza as it was 4,500 years ago in real-time 3D. We discover the theory step by step, first by absorbing the content, then by manipulating it and by choosing our own viewpoints. The technologies and the logic implemented by video games are now being made available to the widest possible public via the Web.



Real-time 3D as a medium at the service of emotion.

Biography

**Jean-Pierre Houdin **

Architect

Born in 1951 in Paris, Jean-Pierre Houdin grew up in Abidjan, in Africa, where his father, an engineer, ran a construction company. As a child, he spent his spare time on construction sites, which is where his interest in civil engineering was no doubt born. Later, in Paris, he enrolled in the architecture department of the Ecole des Beaux-Arts. After he gained his diploma in 1976, he set up in business as an independent architect, a profession that he practiced for twenty years. He was involved in the construction of a large number of residential and office buildings in the Ile de France. At the same time, with his wife Michelle and a friend, he opened a salon cum art gallery devoted to the avant-garde which became an important centre for artistic activity in Paris during the 1980s and early 1990s.

In 1996, he moved to New York, at a time that saw significant developments in the Internet. He learned how to use the web, to draw using the first digital design tools and got involved in the construction of Internet sites. He worked in New York initially then in Paris, where he settled in 1998. In 1999, his father, while watching a television programme about the building of the pyramids, had the sudden insight that the pyramids might have been built from the inside out... He contacted his son Jean-Pierre who, as an architect with experience in 3D design, was able to support him in his research.

In 2005, Jean-Pierre Houdin met with Mehdi Tayoubi and Richard Breitner in the context of the Dassault Systèmes 'Passion For Innovation' sponsorship programme. The Khufu adventure was under way.

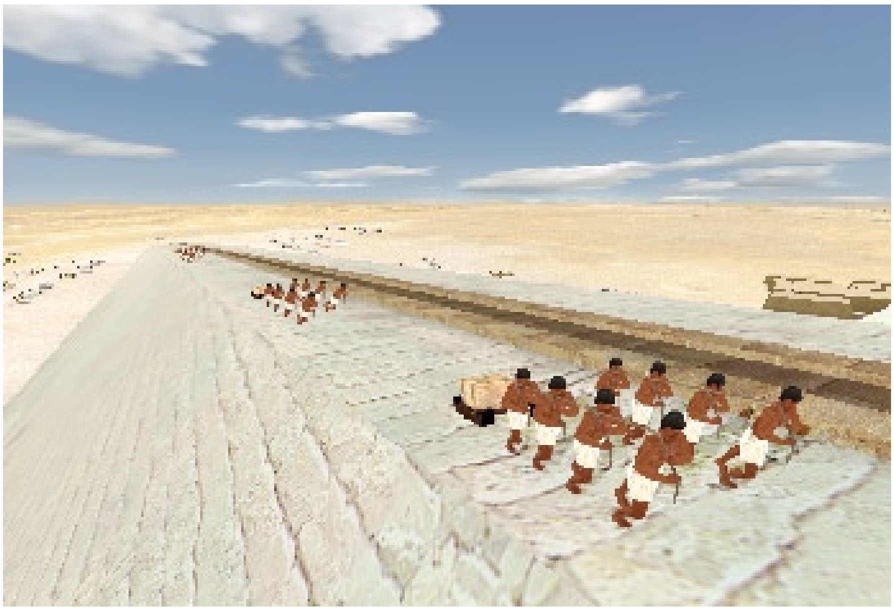
/ Mehdi Tayoubi

Online Marketing & Communications Director

Born in 1974, in Casablanca, Mehdi Tayoubi grew up in a multicultural environment. At the age of 17, this committed innovator filed an early inventor's patent for suitcase design. Moving to Paris, in 1992 he took a preparatory course for the HEC business school before plunging into the art world where he developed a business as a cultural event planner. In 1995, with the arrival of the Internet, he made the link between creativity and technology (creation of an application for art experts, recruitment sites etc.). He put his solid experience in the new media to immediate use in a public relations company where he took charge of the development of Web activities. In 1998 he joined the Web agency Orange Art as a consultant acting on behalf of customers like Lexmark, L'Oreal and Volkswagen. Convinced that the Web would find its true expression in 3D, in 2000 he created the Ultra Orange unit specialised in real-time 3D and launched the first 3D Web applications. From there he went to Dassault Systèmes, the leader in industrial 3D applications, where he became head of the marketing and online communications department, a position that he has held since 2001. He created a multi-disciplinary team, in which autodidacts, engineers, designers and business school graduates came together to stimulate new thinking. With Richard Breitner, he conceived the 'Passion for Innovation' online sponsorship programme in 2005. At the end of 2006, Mehdi Tayoubi and his team launched the first online community for the sharing and exchanging of real-time 3D models, www.teapotters.com. He imagined and piloted the Khufu project, an adventure where real-time industrial 3D applications and expressive real-time 3D would be combined to help and shed light on Jean-Pierre Houdin's theory.

/ Richard Breitner
Web Project Leader

A 44-year-old engineer and aviation enthusiast, Richard Breitner started his professional career in 1987 with SNECMA as an engineer using (already) CATIA, the renowned Dassault Systèmes CAD/CAM software. After a short spell with IBM at the International CATIA Support Centre, he joined Dassault Systèmes in 1992. He held various posts dealing with UNIX maintenance and industrialisation until 1997 when, fascinated by the Internet, he learned HTML in two hours and developed his first Web sites. He was at the origin of the development of the first versions of Dassault Systèmes websites. In 2001 he joined Mehdi Tayoubi's team where he helped to set up the Web Content Management System. As Dassault Systèmes' website evolved, he was given responsibility for its internationalisation. Today the site exists in ten languages. The example of a handicapped colleague, who developed a personal CATIA project on his own, gave him the idea for the 'Passion for Innovation' technical sponsorship programme. 'Passion for Innovation', lent its backing to the Khufu project, where Richard Breitner was particularly active in coordinating the scientific 3D simulations. In addition to the Internet and ancient Egypt, his passions include music, oriental philosophy and classical Japanese poetry. He often says that he will need nine lives to become accomplished in all the fields that interest him.

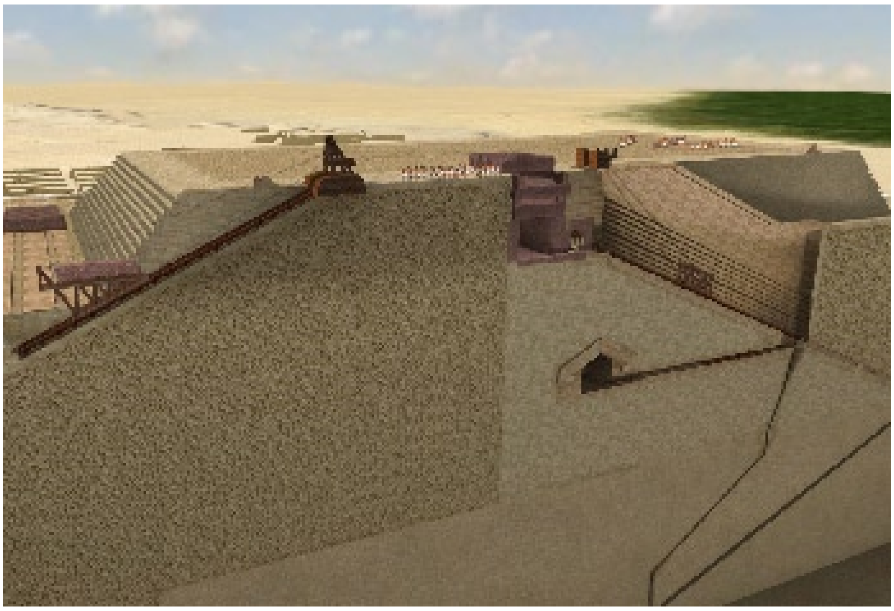


Fifth year of the reign. The two-lane external ramp is used to supply massive amounts of stone for the construction of the first courses of the pyramid. The ramp remained in use during the building of the first 43 metres of the edifice.

Fourteenth year of the reign. Construction of the site has reached the +43 m level, as seen from the North West. The external ramp has reached its maximum level. The interior ramp already has three flights but because of its geometry, it does not affect supply to the site. The ceiling rafters of the King's Chamber are raised to this level by means of the counterweight operating in the Great Gallery.

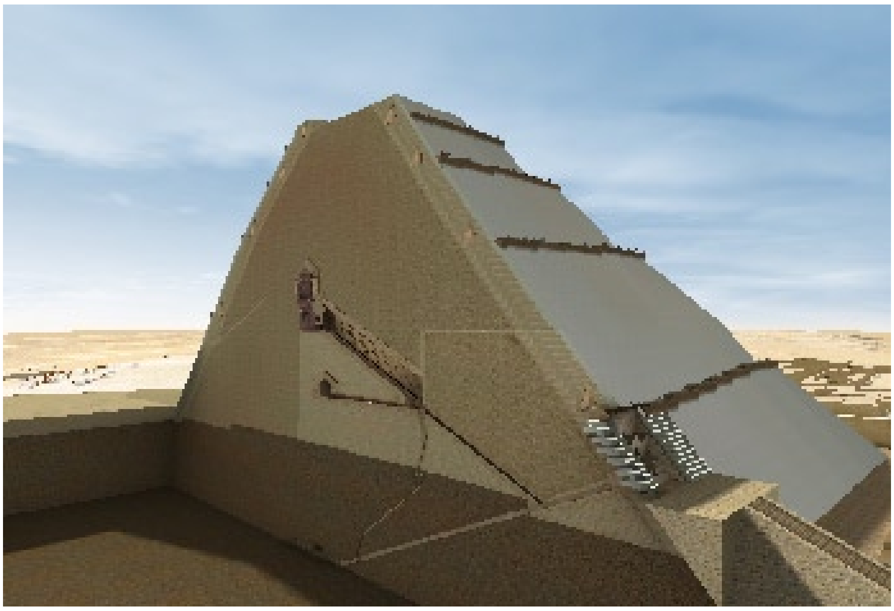
Fifteenth year of the reign. The interior ramp arriving at the +43 m level. It is still not in use for the construction of the pyramid but is already built into the pyramid from level +7 m. To the right, the second degree is under construction, to enable the positioning of the ceilings in the King's Chamber.

Fifteenth year of the reign, the pyramid looks like a two degree pyramid: the first degree, which is definitive, from the base to level +43 m, The second degree stands some twenty metres back from the faces, from level +43 m to level +54 m. This degree is built around the King's Chamber as the chamber is constructed. At level +54 m, the third ceiling is being put into place.



Fifteenth year of the reign. The granite rafters that form the King's Chamber are raised by means of the counterweight and positioned definitively in each of the ceilings. Floor by floor, the King's Chamber is constructed with the help of the counterweight, which considerably reduces the number of workers required.

Fifteenth year of the reign. The site is at levels +43 m and +54 m, seen from the North West. All the rafters of the King's Chamber are now located within the pyramid, either in the storage area on level +43 m or already in place in the first 3 ceilings. The external ramp is still in service and supplies the materials being used to construct the second degree.

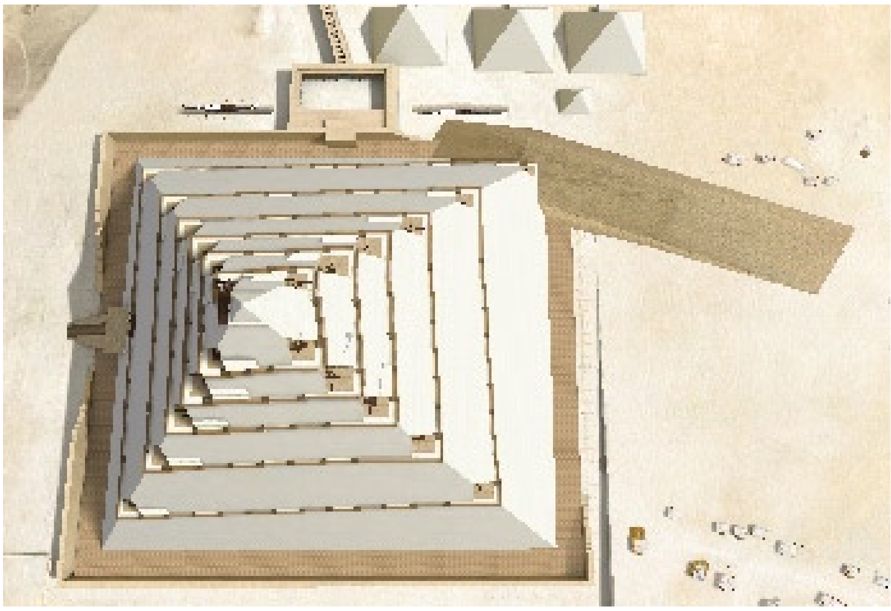


Nineteenth year of the reign, level +113 m is reached. North-South section as seen from the North East. Parts of the interior ramp can be seen embedded in the load-bearing masonry. The King's Chamber is now deeply buried in the mass of the monument. The cracks in the first ceiling have not yet appeared.

Nineteenth year of the reign. The construction, seen from the North West, has reached level +113 m. The King's Chamber has been finished for some time. The pyramid is being constructed with the materials recovered from the demolition of the external ramp. The blocks are now transported to their final positions via the internal ramp.

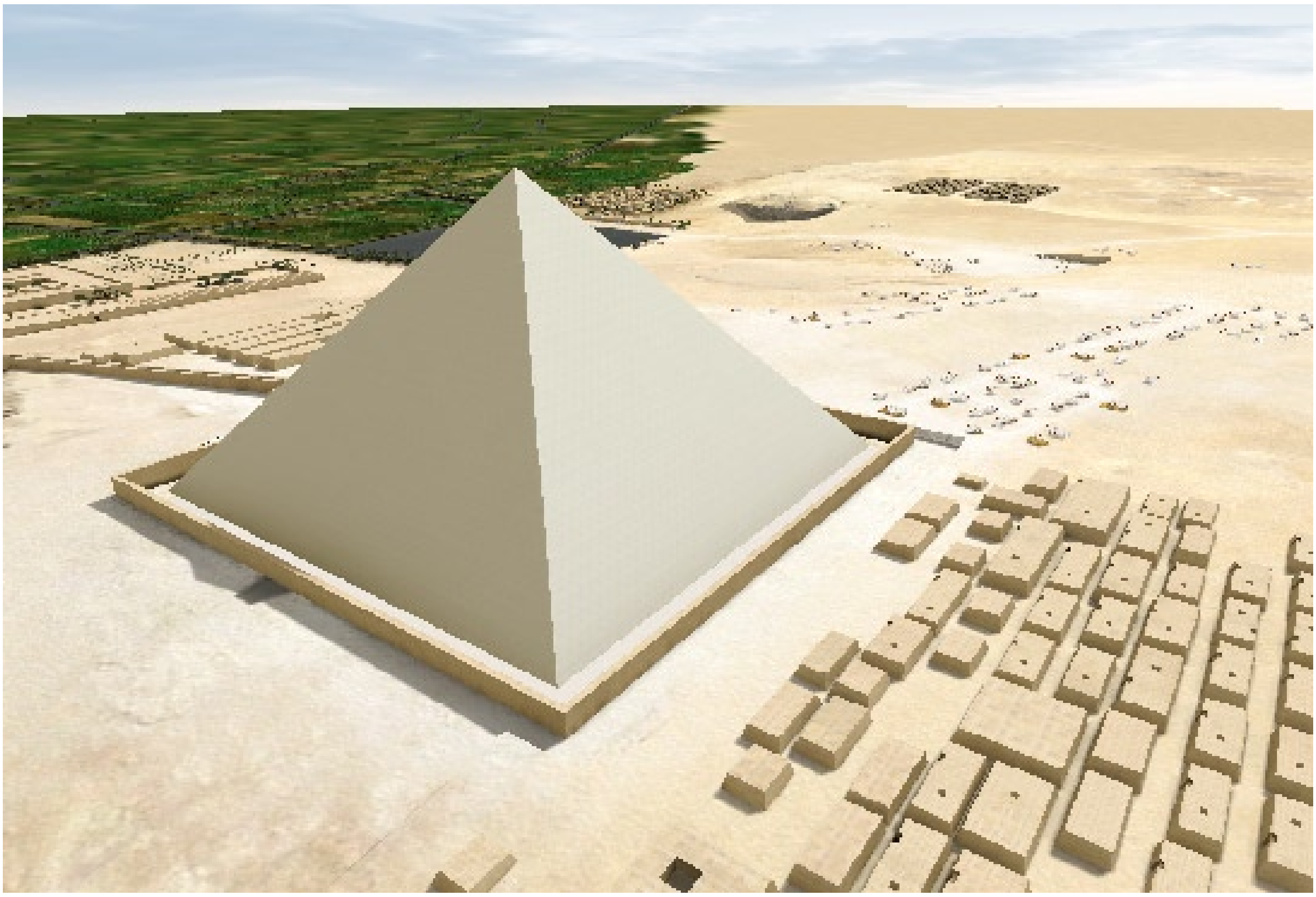
Twentieth year of the reign. Construction of the pyramid is finished. The pyramidion, or capstone, is in place on the summit of the monument.

Twentieth year of the reign. The summit is reached. Finishing work is about to start descending from the summit: the recesses are being filled in, the outside gangway is being dismantled, the last roughly cut facing blocks are being surfaced.



Twentieth year of the reign. Construction of the pyramid is finished. Only the lower part of the frontal ramp giving access to the interior ramp in the South East angle remains. Finishing is about to begin.

Twentieth year of the reign. The pyramid seen from another angle. The main construction is finished, the pyramidion is in place on the summit. Finishing work is about to start from the summit down.



Twenty-third year of the reign. The funeral of Khufu has taken place. The King's mummy now lays in his sarcophagus in the Chamber on level +43 m. The Egyptians had methodically estimated the limits of the cracking of the rafters of the first three ceilings and had judged the Chamber perfectly capable of confronting eternity. Construction work had been completed at the end of the 21st year of the reign with the filling in of the recesses, the dismantling of the outside gangway and the surfacing of the last blocks.

Glossary

Dassault Systèmes is the world leader
in 3D and Product Lifecycle Management (PLM) solutions. DS's software applications and services are used by companies of all sizes in all industries to create and simulate products and processes digitally, and to simulate the resources required for product manufacturing and maintenance. The aim of Dassault Systèmes is to propose solutions that allow individuals to imagine, share and experiment with processes in 3D, in order to promote exchanges of the knowledge inherent to product development across the organisation, from the initial design phase through to operations and maintenance.

Real-time 3D /

consists in displaying images of an environment on a screen in three dimensions while adding the possibility to interact with the content. As in a 3D video game, the user is free to move about at will and interact virtually with the 3D objects which surround him. Real-time 3D thus differs from the 3D normally used in animated movies where everything the spectator sees is pre-calculated and must be watched passively. The spectator of a normal 3D animated movie cannot, for example, interact with the script or change his viewpoint. The quality of display of real-time 3D depends on the power of the hardware and the 3D graphic boards implemented. These boards are increasingly widespread and are evolving rapidly, so the quality of both the graphics and the rendering of real-time 3D environments is likely to improve rapidly to rival that of the pre-ordinated 3D of the animation studios.

- **CATIA for designing the virtual product**

CATIA is used to simulate the totality of the industrial design process, from the initial concept through to product design, analysis and assembly. CATIA meets all technical and density requirements and integrates seamlessly with Dassault Systèmes' full range of PLM solutions.

- **DELMIA for virtual production**

DELMIA is used to create, manage and control production and maintenance processes. DELMIA applications implement the Product, Process and Resources model, unique of its kind, and is applicable to all industrial sectors, in particular in the automobile, aeronautical and naval construction industries.

- **SIMULIA for virtual testing**

SIMULIA is an open multi-physics platform offering realistic simulation capacities for a wide range of traditional or emergent industries. SIMULIA replaces physical tests on products, accelerates innovation and reduces the cost of proprietary software in regard of realistic simulation, while optimising quality and performance. SIMULIA represents the new generation of simulation applications for products with long lifespans.

\ Virtools

Virtools is a major component of the Dassault Systèmes "3D For All" strategy designed to allow the general public to benefit on a day-to-day basis from the advantages offered by real-time interactive 3D solutions.

DASSAULT SYSTEMES
See what you mean

Find the Khufu project at
www.3ds.com/khufu

And also at the ninth Rencontres Internationales de la Réalité Virtuelle, 18-22 April 2007.
Further details at www.laval-virtual.org

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And soon, at the Geode, ground-breaking conferences in real-time 3D open to the general public.

Our thanks to

géode BARCO Visibly yours emissive Land Endemic