B.I.M. AND ARTIFICIAL INTELLIGENCE IN THE DESIGN AND CONSTRUCTION OF EARTHQAKE RESISTANT BUILDINGS

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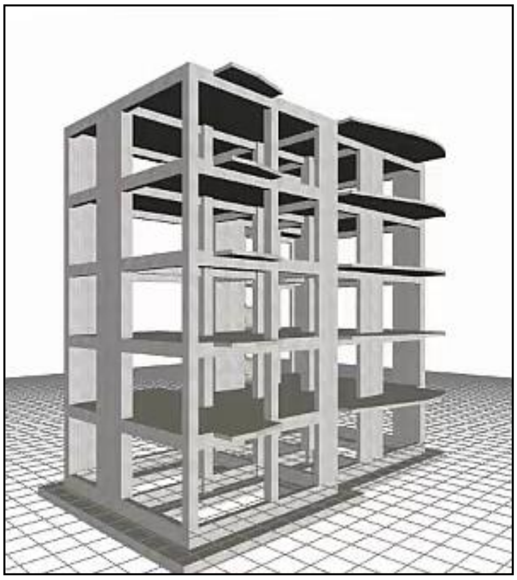
Abstract:

This Article addresses the possibility of using Artificial Intelligence for the Design of Earthquake Resistant Buildings based on the BIM (Building Information Modeling) concept as well as the IFC (Industry Foundation Classes) classification. Moreover are addressed the possibilities of applying them both in Structural Design Analysis as well as in Structural Detailed Design, now, or in the near future.

Appendix II illustrates an example of an advanced holistic BIM concept (HoloBIM™) applied in the Buildings Earthquake Resistant Engineering, specifically applied in the complex field of the Reinforced Concrete that today represents 50% of the worldwide construction industry.

To better inform the reader of this document, Appendix I presents, within the broader context of Human Intelligence, a brief history of the evolution of Artificial Intelligence.

1. INTRODUCTION



Using the latest development of the BIM concept technology, an advanced Structural and Detailed Engineering Design software would require approximately 15 min of Engineer's work to fully recognize the geometry and the other elements of a usual multi-storey, say five-storey, building with a total floor area of 1000 m^2.

Then, that same software, would take another 5 min to fully carry-out the Design Analysis, and subsequently deliver every 5 sec one set of results, including strength analysis and construction cost, for every alternative structure model, so that the Engineer may define in a very short time the optimal solution between alternative scenarios.

The BIM concept, combined with the Virtual Reality technology, provides and satisfies the entire Engineer's training requirements so that he then may educate the software of an Artificial Intelligence Automatic Optimization Application.

2. THE BIM CONCEPT

The term BIM (Building Information Modeling) is today an established acronym in the field of the study and design of building projects. Since the mid-60s, following the extensive use of the CAD (Computer Aided Design) concept in many applications in Architecture, Engineering and Construction (A/E/C) it was gradually understood that digital design models were inadequate to satisfy the multi-faceted actual requirements of a structure such as, the simulation of its behaviour during an earthquake, the natural relations and interaction between the elements of the structure following any modifications of the design assumptions, the detailed quantities take-offs etc (Bellos, 2012).

Both the needs and the benefits of a single conceptual information model of an Object Base (rather than a Data Base) that could "inherit" physical relationships and behaviors, created, only in 1977, the International Alliance for Interoperability (IAI) of the Architecture Engineering Construction (A/E/C) software. A product of this Alliance is the classification and organization of software, concepts / objects / processes of a building structure in an open and unified information model, the Industry Foundation Classes (IFC).

The Building Information Modeling (BIM) concept, from a simple communication possibility between A/E/C applications, established only in 2003, supported by the IFC protocol, made a decisive step towards a digital information model of the physical and functional features of the building, covering its full lifetime, starting from its construction phase, through its maintenance and until its demolition.

A BIM model therefore, is a source of various kind of information that support decision-making related to the "birth", the "life span" and the "death" of a building.

Despite the progress brought by the BIM concept in the construction sector, it does not include specific software application development rules and therefore does not constitute a specific software development technology. Consequently, it cannot include the basic intelligence that will provide to the Engineers intelligent alternative construction scenarios and optimal cost / strength solutions according to pre-selected criteria (Bellos 2012). Such issues should be identified and solved by each software company with its own know-how and technology.

The author of this article, with his own software design and development team, has developed his own technology on an expanded BIM concept that focuses in Earthquake Resistant Reinforced Concrete Buildings under the code name HoloBIM ™ (HolisticBIM)
HoloBIM ™ is not merely a soundly organized Data Base / Building Object Base, but it attempts to models digitally a "living building" that knows how to react and respond to the Engineer's demands and modifications in an optimal way.

The author presents here to the scientific community, to the fellow Engineers and to the Developers of all disciplines the "secrets" of the HoloBIM ™ technology aiming that each of them to move without hesitation and with no doubt about the feasibility of the goal of "automatic optimization".

3. THE ARTIFICIAL INTELLIGENCE IN THE DESIGN AND CONSTRUCTION OF REINFORCED CONCRETE EARTHQUAKE RESISTANT BUILDINGS

There are technical and scientific problems of such complexity that man has not yet reached the point of "instinctive knowledge", as, for example, in the case of conventional car driving, and should therefore be dealt with otherwise. For instance, in the study of the strength and construction of an earthquake resistant building, the Engineer should first comprehend it and then "teach" it to the software.

The engineer has the knowledge and experience to reach the complete of knowledge about the strength of a particular building, but does not have a large number of samples, especially in the field of earthquake resistance, which allow him to accumulate experience that could build reliable automated reasoning (routines) and algorithms to be able to train "machines" (software + hardware) by incorporating to them a relevant "artificial intelligence".

The design of a building has the advantage that it will not be applied immediately, but after some time, for instance after two months, as opposed to the application e.g. of "autonomous/automated driving", where the result of tracking and recognition of the road conditions at a given point in time will be implemented at the very next moment with no time for the human to evaluate and correct it.

So, in the design of a building there is a tolerance of possible errors, because the human will have the time to check and correct any error of the automatic process. A prerequisite, of course, is that the partial results of the study to be clear and easily readable by the average Engineer, and in this respect there is only one way:

The partial results of the study should be given in a graphic illustrative form to allow the swift acting of a well-trained human intelligence, that has already acquired the ability to read the image in a multi-faceted way and compare it "at a glance" with others.

In this respect, a parallel contribution that would play here an instrumental role, would be the way that Universities transfer knowledge to their students. Annex I helps to understand the theory on subjects of this kind of intelligence, and Annex II presents actual practical examples.

Despite the fact, scientific/technical applications are of much more complex and difficult to develop than image and audio processing technologies, they have the advantage of a long lead time up to implementation.

Thus, using Artificial Intelligence in the design and construction of earthquake resistant buildings will allow optimizing structures, according to several criteria, the most important of which are strength and cost.

Another important and exciting difference in Artificial Intelligence of scientific / technical applications is that they do not only monitor what is happening, as for example in "autonomous driving", but they identify the best solutions for strength, energy efficiency, maintenance, etc, always in relation to the respective cost, thus improving the quality of life of the inhabitants of the Earth.

Artificial Intelligence software will soon be able to identify the optimal solution by looking at as many alternatives as needed at a minimum of time, effectively using cloud computing capable of running hundreds or thousands of solutions at any moment in globally distributed processor networks. In this way, a better future for humans can be foreseen, as it is certain that a seismic adversity will take place during the lifetime of any building, in every location.

We foresee that, by 2024, the capability of the technology available will satisfy the need to transfer the engineer's accumulated experience and knowledge to the "machine" in the form of data, algorithms and mathematical / stochastic models, while at the same time they will address this software to provide them with advice and training!

In order for this to happen, it is essential that the software so far has ceased to bear the engineer, asking for continuous repetitions of primary data inputs and estimates of intermediate results. The rules of this art are presented in the section "Rules and example of a single BIM software with Artificial Intelligence capabilities".

A further provision, from the beginning of 2020, is the use of various types of "Seismic Dampers" in earthquake resistant buildings, also referred to as "Seismic Isolation".

To date, this technology has been applied to buildings of critical importance around the world and its results are impressive not only in the increased strength of the buildings but also in their economy. Despite the advantages of seismic dampers, their use is limited and this is mainly due to the difficulty, for the overwhelming majority of the Engineers, of choosing the appropriate types and assessing their behavior.

During the period 2020 to 2024, it is foreseen that Artificial Intelligence technology (or, using another term: Optimisation technology) of building construction will certainly solve this problem and gradually, the use of dampers by practising engineers will grow exponentially.

In the near future, it is anticipated that, in addition to optimizing the study, the software will also be able to optimize the construction method, in line with the automation capabilities of the materials and services industry of that time.

4. RULES AND EXAMPLE OF A SINGLE BIM SOFTWARE WITH ARTIFICIAL INTELLIGENCE CAPABILITIES

All of the above may sound as mere theories, while the experts demand to read something real, something already implemented that demonstrates in a simple way all the previous theory. This is the main reason that pictures from the example of HoloBIM ™ are being included in the development methodology text.

A comprehensive application of Artificial Intelligence consists of four main stages:

(1) Input of the problem data.

(2) Data processing.

(3) Solving the problem.

(4) The presentation of the problem solution.

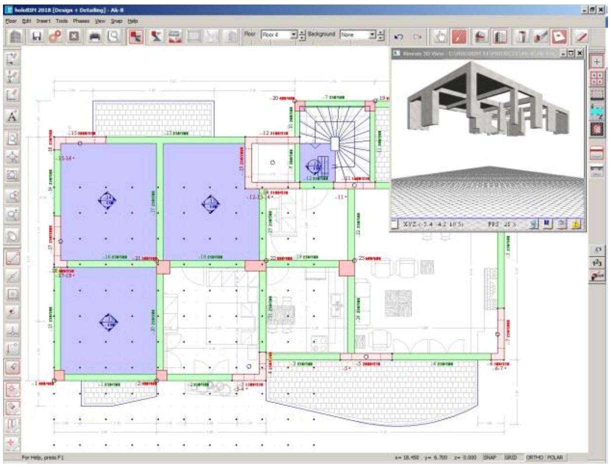
Let's take a closer look at these steps:

4.1. Input of the problem data

Classification and importing data are the starting point of any software. If this phase is successful, 40% of the success of the project will have been achieved.

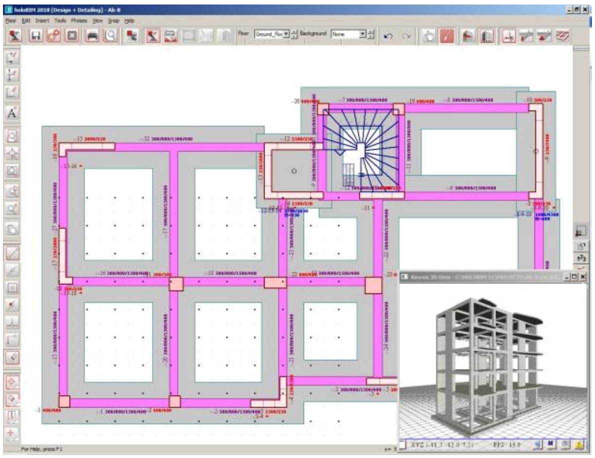
The importance of this phase is illustrated by the very simple saying: “garbage in, garbage out”, meaning “if you input garbage, the output will be garbage.”

Example: STRUCTURAL FRAME INPUT (Duration 15 min)



Superstructure Input

Columns, beams and slabs are input using as a background DWG/DXF format architectural drawings



Foundation Input

For each type of foundation, footings are automatically placed under the columns and in this way the frame’s description is completed.

The following steps are to be followed in order to achieve this:

a) Identification of the necessary information needed to accurately define the problem (not one piece of information less, but also not one piece of information more).

b) Procedure for entering the necessary information

The general rules of the Interfaces apply here, where the relevant shape is very useful to also be displayed graphically so that the user can compare the different sizes to each other.

c) Data validation of input

A good Interface must incorporate an intelligent and reliable data validation process. The best way to validate the data is by the users themselves, and the best way for a person is to see the data graphically displayed as an image or in a chart format. In this way the user can evaluate at a glance the integrity of the data. As long as the software is still in the development phase, developers themselves effect the evaluation "at a glance" by debugging the program.

d) Presentation of the whole problem

At the end of the data input process, it is necessary to present the whole problem in a way that the user can immediately perceive it, in order to ensure the correctness of the data they gave.

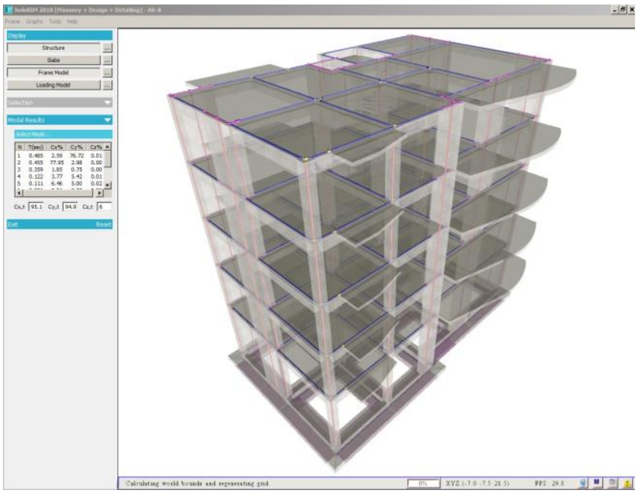
e) Procedures for modifying data

It should always be possible to easily and visually effectively modify one or more data items at any stage of the program.

4.2. Data Processing

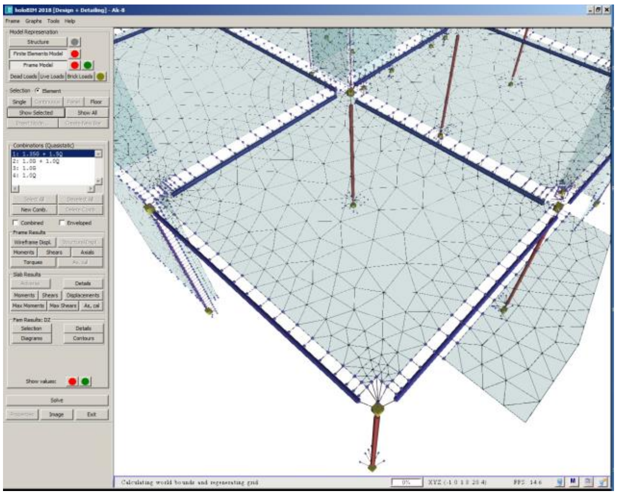
When data entry and any modifications are completed, the models on which the problem solution shall be based will be created (Konstantinidis et al., 2013). These models may be mathematical, with linear or implicit functions, or statistical or comparative.

Example: CREATION OF THE SPACE FRAME (Duration 30 sec)



Generation of a Space Frame Model

Automatic generation of the space model with finite linear elements. In this case, the model and the structural frame, in a transparent form, are simultaneously displayed to confirm that the structure has been correctly modelled.



Finite Element Space Frame

Automatic generation of the space model using linear and surface finite elements.

The sequence of the necessary steps:

a) Create models emulating the problem

   To carry-out calculations or comparisons, it is necessary to create mathematical models.

b) Compare each individual model with other previous models of the same subject.

   The comparison helps to define the importance of each individual model used, so that, ultimately, to produce optimal and more accurate models.

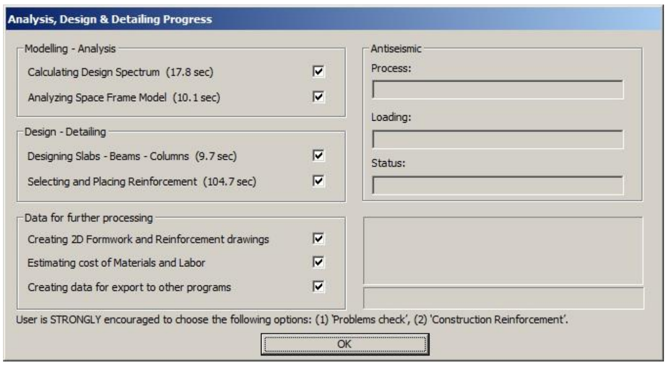
c) Perform trial runs of each individual model and compare the results with previous results.

   The purpose is to validate each individual modeling because the final solution of the problem shall derive from the whole set of modelings.

4.3. Solving the problem

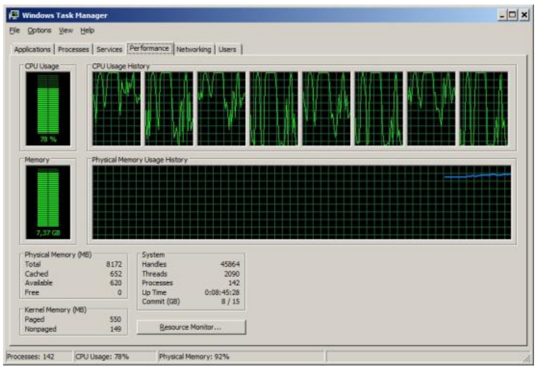
The problem is solved through the individual solutions of the models used to emulate the problem (Konstantinidis et al., 2013).

Example: STATIC AND DYNAMIC ANALYSIS, DIMENSIONING, REINFORCING, ETC. (Total duration 5 min)



Solving

Run all the models, perform dimensioning, select rebars, run serviceability checks, etc.



Solving finite elements model

The model includes a system of 180,000 equations with 180,000 unknowns and is solved in 10'' using simultaneously all 8 mathematical processors

a) Solve the problem using the new modelings and the new accurate algorithms (Konstantinidis et al., 2013, Bellos et al., 2017)

   The term "new" denotes the continuous evolution of the BIM application incorporating Artificial Intelligence capabilities that can be called automatically as the application is running.

b) Compare with older approximate but safe algorithms

   It is recommended that the newer and generally more accurate algorithms be compared with other, older and tried algorithms in order to compare the order of magnitude of the new results and thus avoid eventual gross errors.

c) Correct/optimize the new, accurate algorithms

   The software needs to be constantly improved because the perfect never reaches perfection. Improvements include an increase of speed, which is what enables implementation of Artificial Intelligence's capabilities, which always involve a large volume of processing and therefore require near-instantaneous speed.

4.4. Displaying the problem's solution

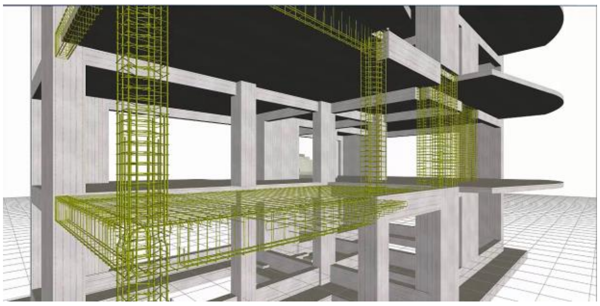
The most important art of an Artificial Intelligence application is to present the solution simultaneously with presenting the problem so that the user has no doubt about either the problem he has set or the solution that the software has provided. Creating a presentation of the problem and its solution is important and worthwhile first of all for the developers and application analysts themselves who should be the first ones to see how the application runs to be able to correct and improve it.

Example: UNLIMITED RESULTS (duration of each 5 sec)

	Quantity	Materials Cost	Labour Cost	Materials Total Cost	Labour Total Cost	Total Cost	Total Cost per m^3
Concrete	268.13 m^3	75.00 €/m^3	0.00 €/m^3	20109.74 €	0.00 €	20109.74 €	75.00 €/m^3
Formwork	2109.84 m^2 (7.9 m^2/m^3)	0.00 €/m^2	12.00 €/m^2	0.00 €	25318.04 €	25318.04 €	94.42 €/m^3
Stirrups	8807.49 Kg (32.8 Kg/m^3)	0.60 €/Kg	0.20 €/Kg	5284.50 €	1761.50 €	7046.00 €	26.28 €/m^3
Rebars	24129.66 Kg (90.0 Kg/m^3)	0.50 €/Kg	0.12 €/Kg	12064.83 €	2895.56 €	14960.39 €	55.80 €/m^3
Insulation	0.00 m^3	210.00 €/m^3	30.00 €/m^3	0.00 €	0.00 €	0.00 €	0.00 €/m^3
Panel Material	0.00 m^3	100.00 €/m^3	0.00 €/m^3	0.00 €	0.00 €	0.00 €	0.00 €/m^3
Grossbeton	0.00 m^3	75.00 €/m^3	30.00 €/m^3	0.00 €	0.00 €	0.00 €	
Steel elements	0.00 Kg	2.00 €/Kg	1.00 €/Kg	0.00 €	0.00 €	0.00 €	
Sum				37459.06 €	29975.10 €	67434.16 €	251.50 €/m^3

Construction Cost

Summary table showing quantities and cost of materials and workmanship for the construction of the structural frame



Confirmation of the re-bar tables

Quantities confirmation "at a glance"

The presentation should mainly consist of images for easy reading by humans (Konstantinidis, 2010), and should consist of the following sections:

a) The central presentation of the problem and the solution

The centrally appearing presentation of the solution should be the smallest possible and in no case will it enter into details, it will include what the average user would like to see.

b) Presentations of individual solutions

These presentations will be optional and when the user asks for one of these, they should be able to see the individual models and individual solutions used to arrive at the overall solution.

c) Ability to evaluate the solution by the user.

This feature will not only be useful to the user engineer but will allow developers themselves to confirm the accuracy of the ratings and to register them appropriately.

Annex II presents some of the many individual solutions from the virtually unlimited outputs of HoloBIM ™ to demonstrate the possibility of in-depth evaluation of the solution by the Engineer. These images, from the software's Virtual Reality technology, are also an example for the necessity to provide a new concept for the future training needs of both students and professional engineers.

5. Epilogue:

This article addressed the modern technology of the design and construction of buildings using software based on the BIM / IFC concept, combined with the advanced logic of a holistic artificial intelligence, specializing in reinforced concrete earthquake resistant buildings. It has been shown that the study and construction of buildings are now being put on a new base, where in the first instance the “machines” train the humans who are now called upon to discover the optimization parameters and algorithms. Then, humans are in a position to train machines to do automatic optimization, as these machines take over the laborious, repetitive recalculation and redesign work, effectively approaching optimal strength and cost solutions.

ANNEX I: HUMAN AND ARTIFICIAL INTELLIGENCE

I.1. THE HUMAN INTELLIGENCE

If GOD created Man in His image and likeness, according to the Ancient Traditions, surely then Man made the Machine as his own simulation.

From the first tools to today's automata (robots), man only does his best to discover his strengths and make up for his weaknesses. And to that lies "The Objective Intelligence".

The scholar definition of Human Intelligence, is the whole of human cognitive abilities, namely perception, memory, association, imagination, attention and intellect, and in particular the ability to adapt to new situations and the ability to perceive similarities, differences and relationships

Observing Nature and their body, humans discover their laws. They learn them by experience, and, by learning them, they can adapt and construct, satisfying their needs and thus developing the type and degree of their Intelligence.

In fact, a few days after their birth, humans have already begun to discover and use their first tools: touch, taste, odor, hearing and vision.

In a few months, they begin to distinguish and arrange the sounds and images, and communicates with their environment.

Soon after, they begin to walk, and later to speak one or more languages, self-trained within the family / social environment where they exist.

As a child, playing and at school (and/or elsewhere), through personal research and experimentation (work) they will receive dense information to be transformed into knowledge and experience. Then they will begin to understand, more or less, that in order to further evolve, they need logic and morality that they must conquer. Thus they learn to use their memory, to classify information, to do mathematical acts, to control themselves, to communicate with their likes, and to philosophize..

Thus, speaking succinctly, the adult human reaches the following strong and weak points:

<u>Strong points:</u> They dispose of a global perception and knowledge of the environment in which they live, being able to reach an immense number of conclusions, they are able, with a thought, to form a large number of images and they dispose of a rational thinking to distinguish what is beneficial to them and their environment. Finally, they dispose of an imagination that can open up for them new horizons of Reality.

<u>Weak points:</u> Their memory is limited, the speed they perform mathematical operations too low, their brain gets easily tired and is vulnerable to feelings, which can easily limit their correct judgment.

> *Artificial Intelligence is the inventions that emulate the functions of human intelligence to replace, more or less, its weak points with technological devices, i.e. software and hardware systems.*

I.2. A BRIEF HISTORY OF THE ARTIFICIAL INTELLIGENCE

Man, as an intelligent being, conceived the numbers, then invented the addition, the simplest algorithm we all learn from the early school years, then devised the abstraction. The multiplication algorithm followed, and then that of the division. He then devised the first-order equation-solving algorithm and then the first-degree equation system solving algorithms. Much of our current mathematics education is based on these simple algorithms. Computing engines work exclusively with them!

Although “large” computers were designed and built during the World War, only in the 1960s, small electric battery calculators appeared, incorporating the algorithms of the four arithmetic operations into electrical circuits. So we started to have the calculators, the first Artificial Intelligence machines of that period. After a few years, these machines also gained memory, resolving another human problem, memorizing.

In the 1980s, the first electronic microcomputers, with sound and graphics capabilities, emerged. As they were now accessible to everyone, the rapid development of software that solved complex problems using many numerical operations and a lot of memory began. But the main achievement was that they translated the results into images (raster format for screen and printer projection and vector format for drafting using the newly-born pen plotters of those days) enabling people to understand the solutions of their problems with the most effective way of for their intelligence: the image.

Today, in the year 2018, we have electronic computers with their memories, their mathematical and graphic processors, laptops, tablets, and smart phones with ultra-high-resolution displays, printers, plotters, etc, to which we have incorporated much of our human intelligence that provide us with the tools to do a lot of work.

Text editors (such as “Word”), spreadsheets (such as “Excel”) have become an integral part of our daily work. Database technology has changed the way information is archived, Multimedia technology has changed the way people are educated and entertained, CAD technology has changed design, GIS technology has changed the way in which cities' utilities are being recorded, and today Virtual Reality technology is progressing to stereoscopic 3D and 'real' 4D representation.

At the same time, mankind takes steps of universalism and by mutual agreement has created the Internet, the standards of video, images, sound etc.

As we have seen historically, we have made progress in both hardware and software technology, a progress that is growing exponentially over time and has already solved many of our day-to-day problems but also of our visions.

For example, a system of robotic arms assembling a car, a 3D printer that "prints" an airplane's components, an autonomous car driving system, a face recognition system, are Artificial Intelligence applications of the present era, but they are as important as was the pocket computer, fifty years ago.
So if we want to give another definition of Artificial Intelligence Technology we could say:

Artificial Intelligence Technology is the combination of software and hardware that automatically solves (by itself) a complex problem without the need for any other human intervention.

I.3. ARTIFICIAL INTELLIGENCE TODAY

Artificial Intelligence, at a given time, is in fact a synthesis of the past conquests of this technology, combined with new human awareness of the new problems that he faces and tries to solve.

Here we are today where technology has reached a phase of maturity, so that in some areas the way to Artificial Intelligence has been opened to such a level that in some cases it can overcome the human ability in speed and complexity.

I will bring a distinctive example: Autonomous driving.

Here we have to clarify that Artificial Intelligence does not compete with humans, but it is a substitute for them. Let's not forget that this technology has been created by humans, humans with specialization and talent to handle this technology in the same way that others have the gift of mathematics, others of sports qualifications, others of philosophy, others of commerce, etc.

> *The greatest advantage that man has is that he can imagine the future, discover new methods, overturn the data when needed, and, above all, make the right decision, as long as he has all the data at his disposal, combining logic with ethics.*

The issue of logic and morality, however, escapes from the field of this article, without ever stopping it from seriously considering logic and morality that have not yet (!) been automated so that they can evaluate and be objectively evaluated.

However, artificial intelligence does not belong to the fruits of the tree of the knowledge of good and evil, nor does it constitute a moral dilemma. Even with a simple pencil one can commit a crime!

> *"General" Artificial Intelligence cannot exist; there are only its applications. This gives both the highest degree of security but also of responsibility, and the security measures must be targeted there in the case of its applications: on all critical security issues, at least in people's lives, software should not decide, but humans.*

I.4. THE EXAMPLE OF AUTONOMOUS CAR DRIVING

Most of today's Artificial Intelligence technologies typically have a relatively small integration core mainly in the areas of image recognition, sound recognition, and object positioning in space. The combination of image recognition algorithms with the incredibly large amount of archived images and sounds in stand-alone format or in combination with video content on the Internet creates a favorable software training environment.

However, the basic algorithm is that of image recognition, which is a relatively simple algorithm based on comparison with standard images e.g. traffic signs images and standard sounds, such as car horns.

This algorithm is then specialised for various situations as for example in the classification of the sign type e.g. STOP signal, etc.

At today's computer speeds, capturing images from sensors and then processing them from the PC is almost instantaneous, and then identifying the objects surrounding the vehicle, for example signs, lights, sidewalks, nearby vehicles, etc., as well as determining their relative position in relation to the car is again almost instantaneous, so the software's conclusion at every moment simulates what would be the perceived by the human driver who would use their two eyes , but would also have many mirrors to see the whole environment.
The basic entity is the state at one moment, the state that has happened in the past, say, one thou-

sandth of a second before. Following this moment and compared to the previous moments and combined with the car's position as shown by the GPS system and the operating condition of the car, the software decides what to do on the brakes, on the accelerator, on the lights etc.

We essentially have a simulation of the instinctive function of the human brain in detecting the road environment and the decisions / movements that a human would make.
However, the decision must be taken by the software and at the critical moments there is no time for the software to pass the control over to the human being because the inertia of human awareness of the situation is significant.

But the advantage of humans is that they possess the experience of driving correctly and they are able and must embed it in the software of autonomous driving until the last detail and it is certain that in a few years, this knowledge will have passed to the machines almost 100%.

This same human experience teaches humans that despite the knowledge of proper driving, they make implementation errors, for instance due to fatigue leading to accidents, they have therefore decided to train the machines with their own experience by using the capabilities of the machines, to not getting tired or if they “get tired” of passing control to another machine or even to the humans themselves.

ANNEX II: SELECTION OF 21 INDIVIDUAL RESULTS AMONG THE THOUSANDS OF THE HoloBIM™ EXAMPLE OUTPUTS

Important clarification: Input of the building structural frame elements took about 15 minutes of an engineer's time while the complete analysis and detailed design was automatically executed by the software in 5 minutes. The following screens are just outputs of these solutions whenever and to the extent that the engineer wanted to check the analysis and/or accuracy of the program, or to train themselves. The creation and display of each of these outputs took 5 to 30 seconds.

(1) SUMMARY QUANTITY TAKE-OFFS FOR MATERIALS AND LABOUR

1.1 Concrete Quantity Take-off (m³)

Level	Over-ground structure			Foundation		Sum (m^3)
	Columns	Beams-Slabs	Stairs	Foundations	Grossbeton	
Floor 4	21.28	34.70	1.76			57.74
Floor 3	21.28	34.70	1.76			57.74
Floor 2	21.28	34.70	1.76			57.74
Floor 1	21.28	34.70	1.76			57.74
Ground_Floor	29.42	34.70	1.99	70.21		136.32
SUM (m^3)	**114.54**	**173.50**	**9.01**	**70.21**		**367.26**

1.2 Formwork Quantity Take-off (m²)

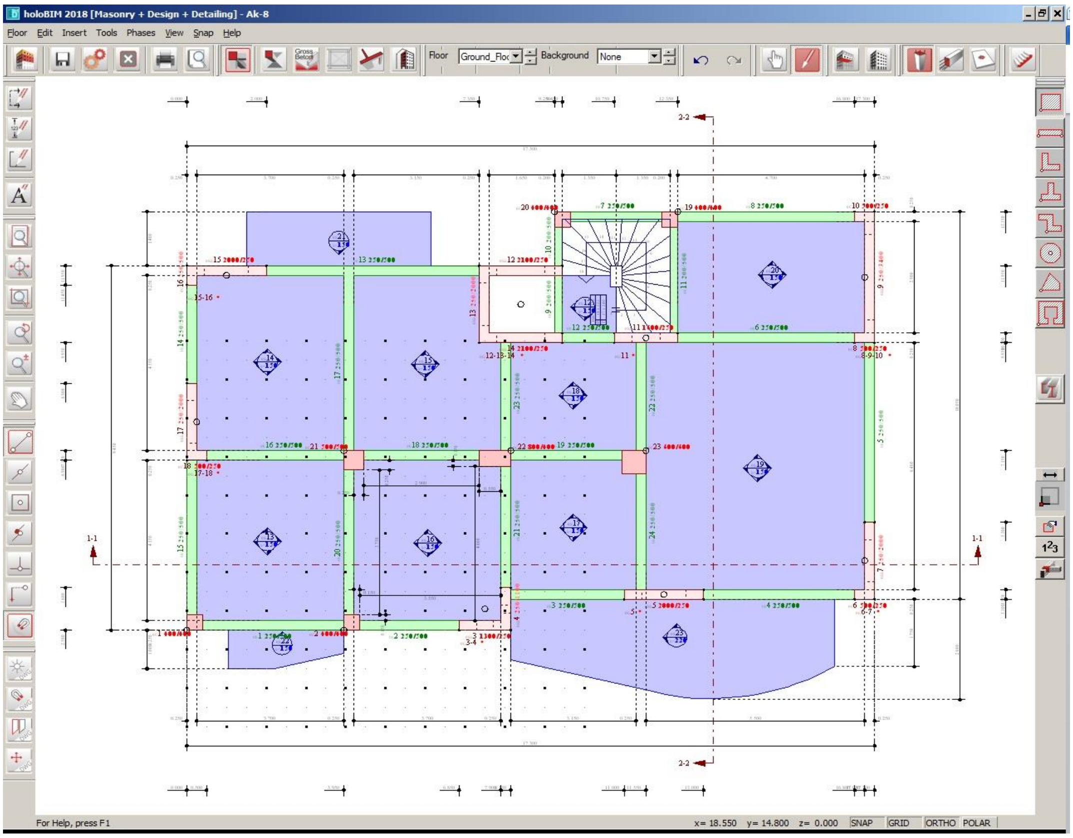
Level	Over-ground structure			Foundation		Sum (m^2)
	Columns	Beams-Slabs	Stairs	Foundations	Others	
Floor 4	175.08	241.61	10.87	-	-	427.57
Floor 3	175.08	241.70	10.90	-	-	427.68
Floor 2	175.08	241.70	10.87	-	-	427.66
Floor 1	175.08	241.70	10.90	-	-	427.68
Ground_Floor	245.41	241.70	14.65	144.01	-	645.77
SUM (m^2)	945.73	1208.42	58.21	144.01		**2356.36**

1.3 Reinforcement Quantity Take-off (m)(kgr)
1.3.6 All

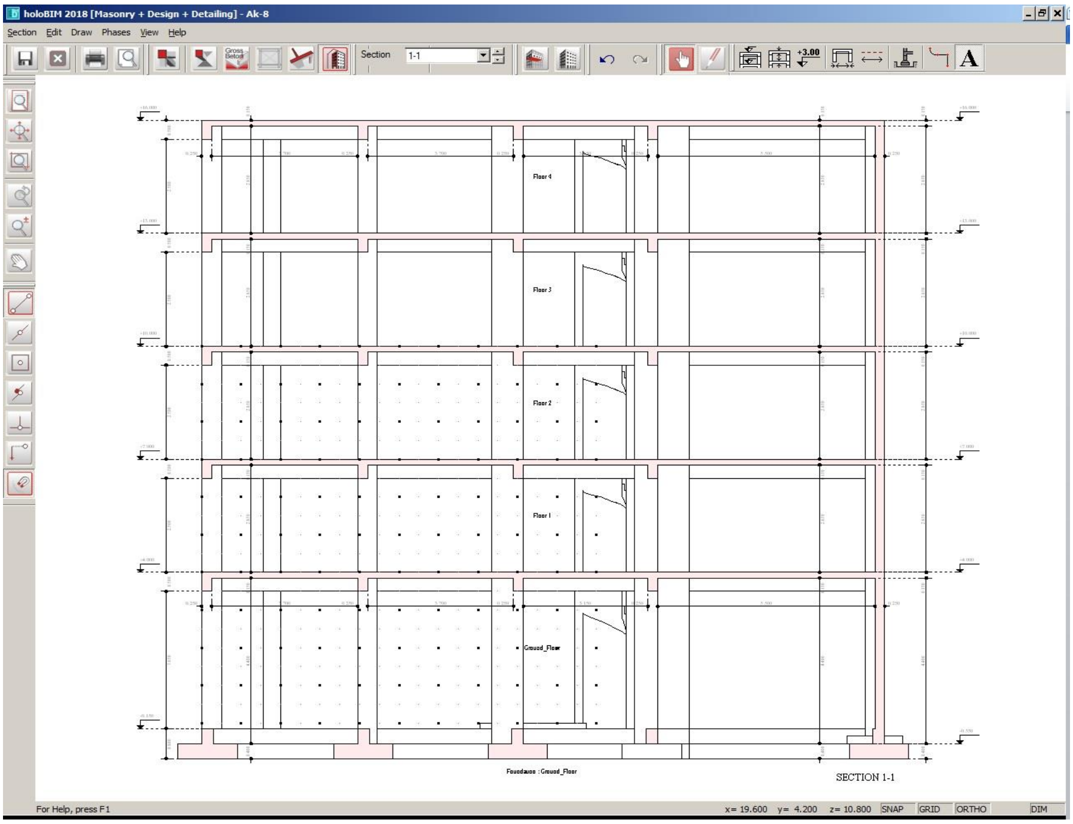
		Over-ground structure			Foundation			Sum	
Rebars		Slabs	Beams	Column	Slabs	Footings	Beams	(m)	(Kgr)
	Ø4	-	0.95	-	-	-	-	9.66	0.95
	Ø8	4499.65	-	-	-	-	-	11403.54	4499.65
	Ø10	866.47	-	3642.54	-	-	-	7313.44	4509.01
	Ø12	-	-	-	-	215.87	2012.80	2510.29	2228.67
	Ø14	-	3876.07	110.34	-	-	8.54	3301.61	3994.95
	Ø16	-	171.07	4365.29	-	-	387.63	3116.45	4923.99
	Ø18	-	896.44	-	-	-	2107.49	1501.96	3003.93
	Ø20	-	678.72	3701.35	-	-	302.98	1895.97	4683.05
Rebars sum		5366.13	5623.25	11819.52	-	215.87	4819.44	31052.92	27844.20
Stirrups		Slabs	Beams	Column	Slabs	Footings	Beams	(m)	(Kgr)
	Ø8	-	1495.36	6381.09	-	-	-	19961.41	7876.45
	Ø10	-	13.47	-	-	-	725.84	1199.12	739.30
	Ø12	-	20.04	-	-	-	-	22.57	20.04
Stirrups sum		-	1528.86	6381.09	-	-	725.84	21183.10	8635.79
SUM		**5366.13**	**7152.12**	**18200.61**	**-**	**215.87**	**5545.27**	**52236.01**	**36479.99**

The relevant detailed quantity take-offs cover 156 pages

(2) CARPENTER'S FORMWORK DRAWINGS

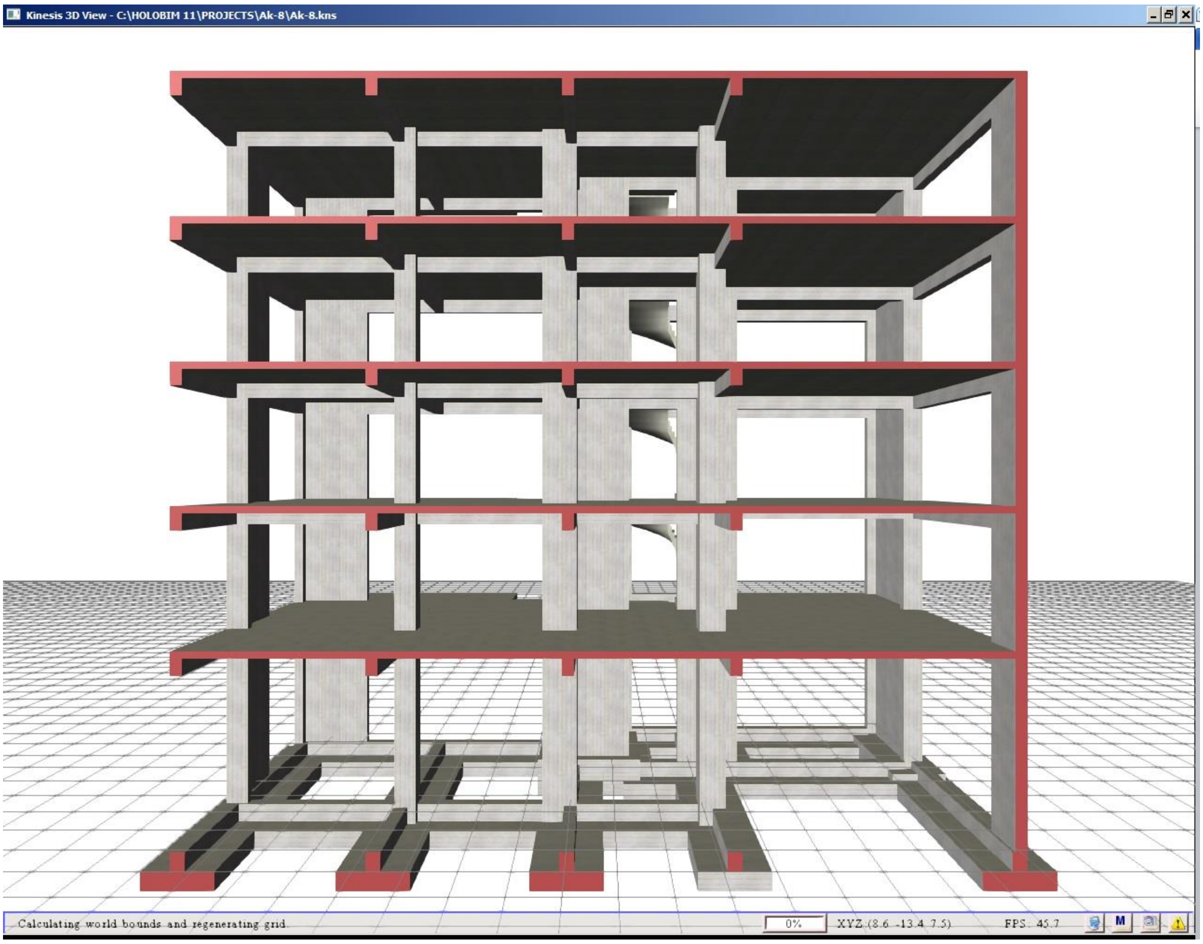


(3) CARPENTER'S DRAWING SECTION 1-1

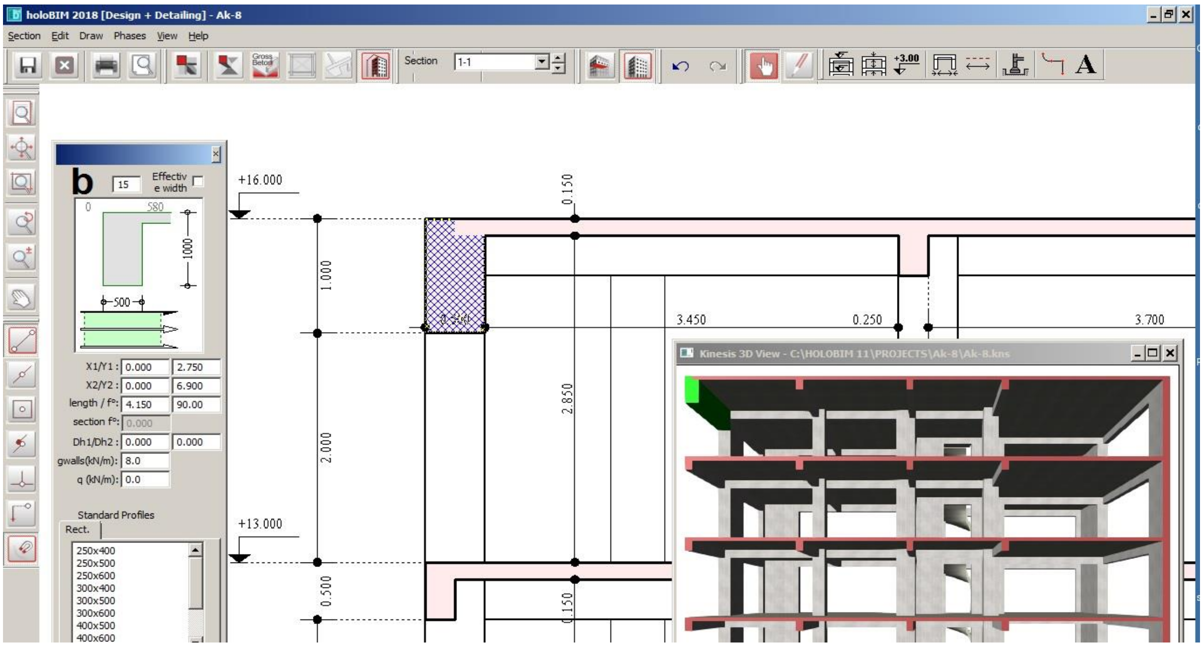


(2), (3) Drawings with coordinates and dimensions have been automatically generated

(4) CARPENTER'S 3D DRAWING SECTION 1-1

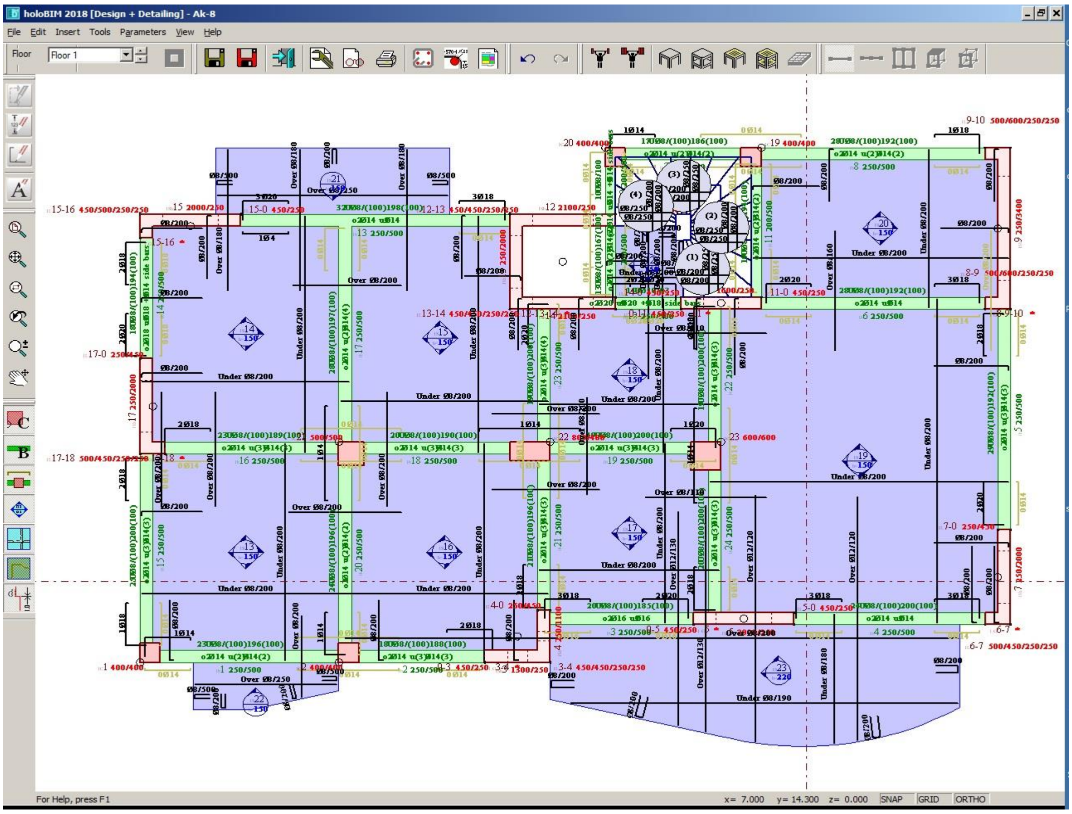


(5) 2D-3D-…-nD STRUCTURAL FRAME MODIFICATION

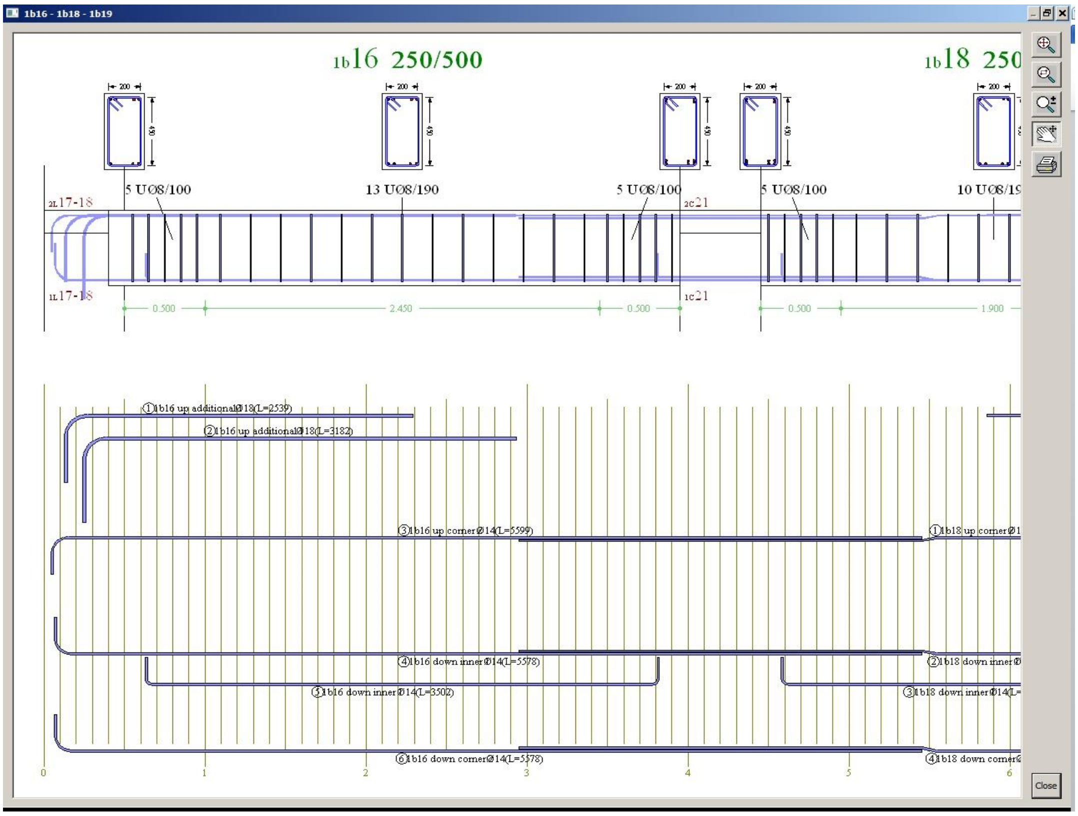


(5) Modification of a structural frame element, e.g. beam b15, may be effected on the floor plan or on the cross-section through the Interface or internally, by a procedure not accessing the Interface. Every modification instantly updates each 2D and 3D drawing, the modelling, the quantity take-offs, the cost, etc.

(6) REBAR FIXER'S FORMWORK DRAWINGS

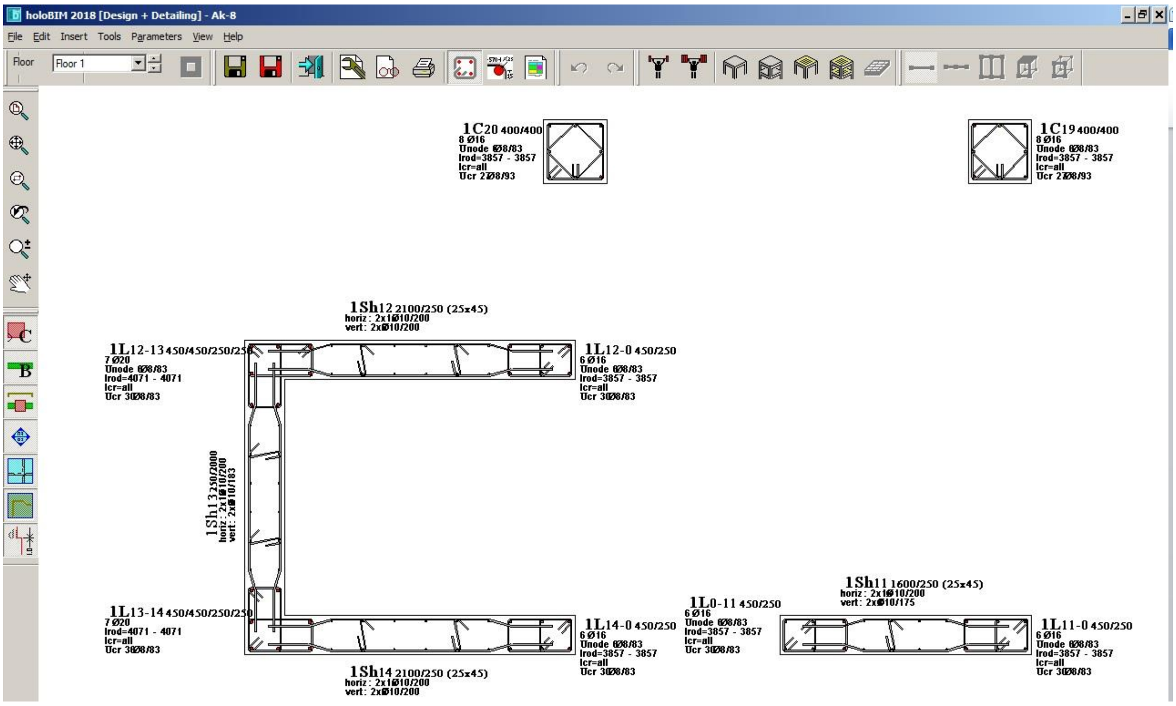


(7) CONTINUOUS BEAM 1b16-1b18-1b19 DETAILING

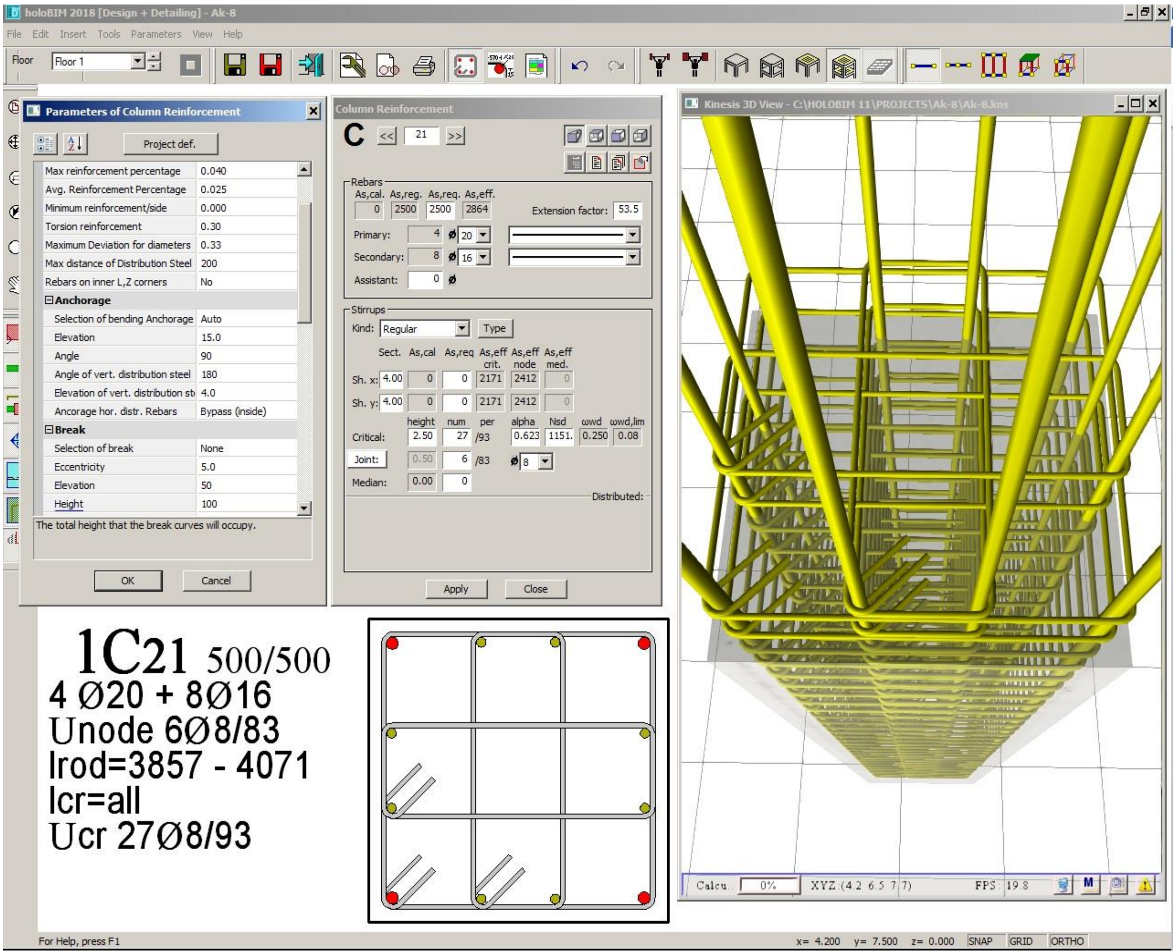


(6), (7) Formwork and detailing drawings have been automatically generated.

(8) STAIRCASE COLUMN DETAILS



(9) COLUMN REINFORCEMENT MODIFICATION



(8) Column details have been automatically generated (9) Manual modifications are effected as required using one or more of the hundreds of parameters

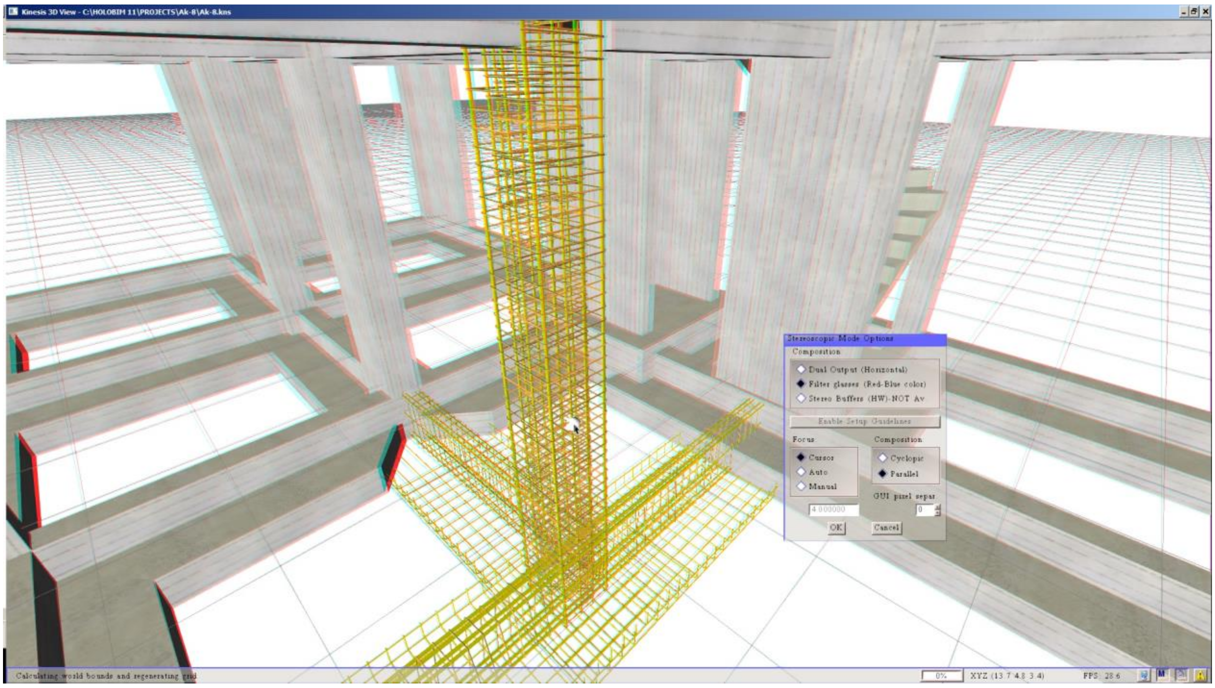
(10) REBAR LIST/ORDER

Project: Ak-8

Beams: Ground Floor

Elem.	Description	Sketch	Pin (mm)	L (mm)	Quant. (v)	Length (L*v) (m)	Diam. Ø
0b1	down	177 3280 177	60	3602	2	7.20	14
	down	242 5282	190	5480	2	10.96	14
	up	5303 272	190	5530	2	11.06	14
	Additional Up	1353 271	190	1580	1	1.58	14
	Stirrups Regular	450 200 200 450		1508	23	34.73	8
0b2	down	4370		4370	2	8.74	14
	down	4370		4370	2	8.74	14
	up	4470		4470	2	8.94	14
	Additional Up	2411		2411	1	2.41	18
	Additional Up	3240		3240	1	3.24	18

(11) 3D REAL-TIME STEREOSCOPIC DISPLAY

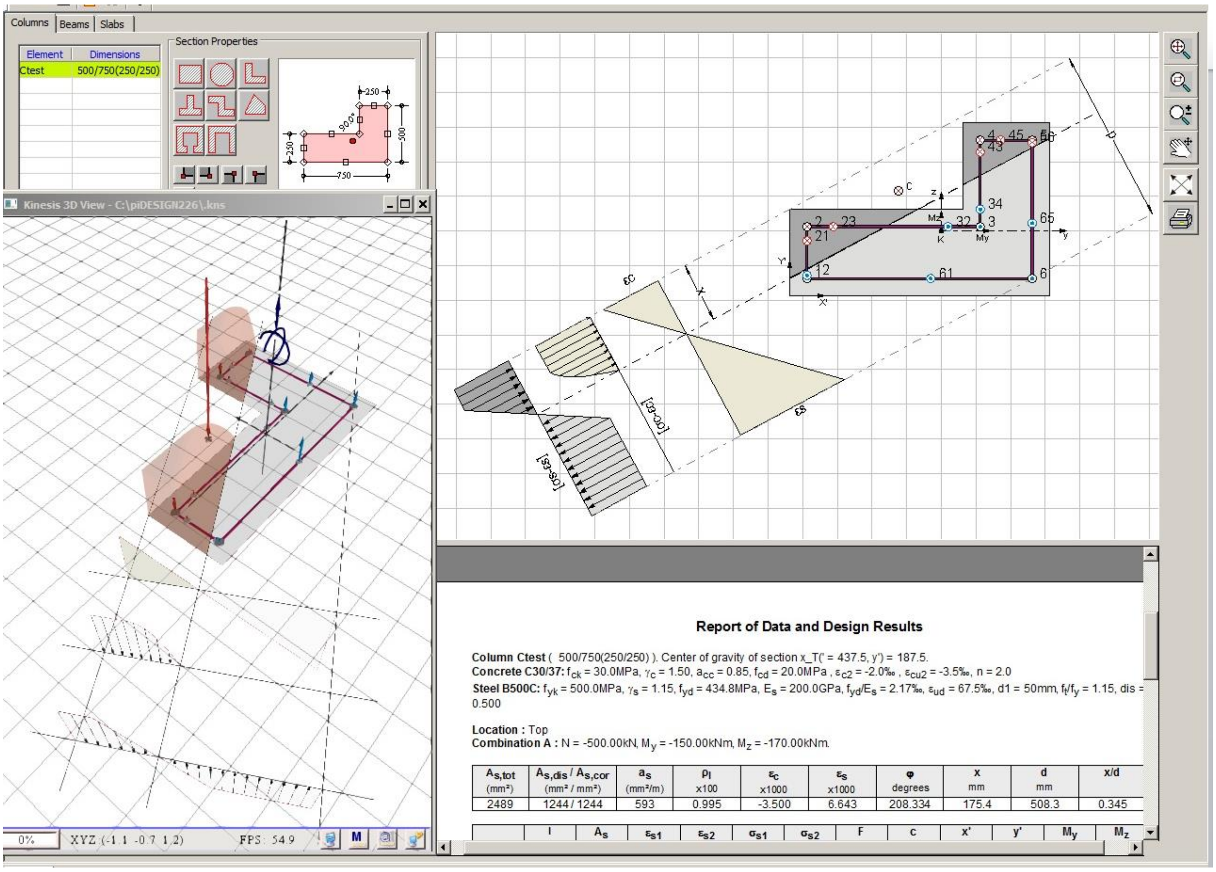


(10) Rebar lists are visually confirmed and are therefore undoubtedly correct

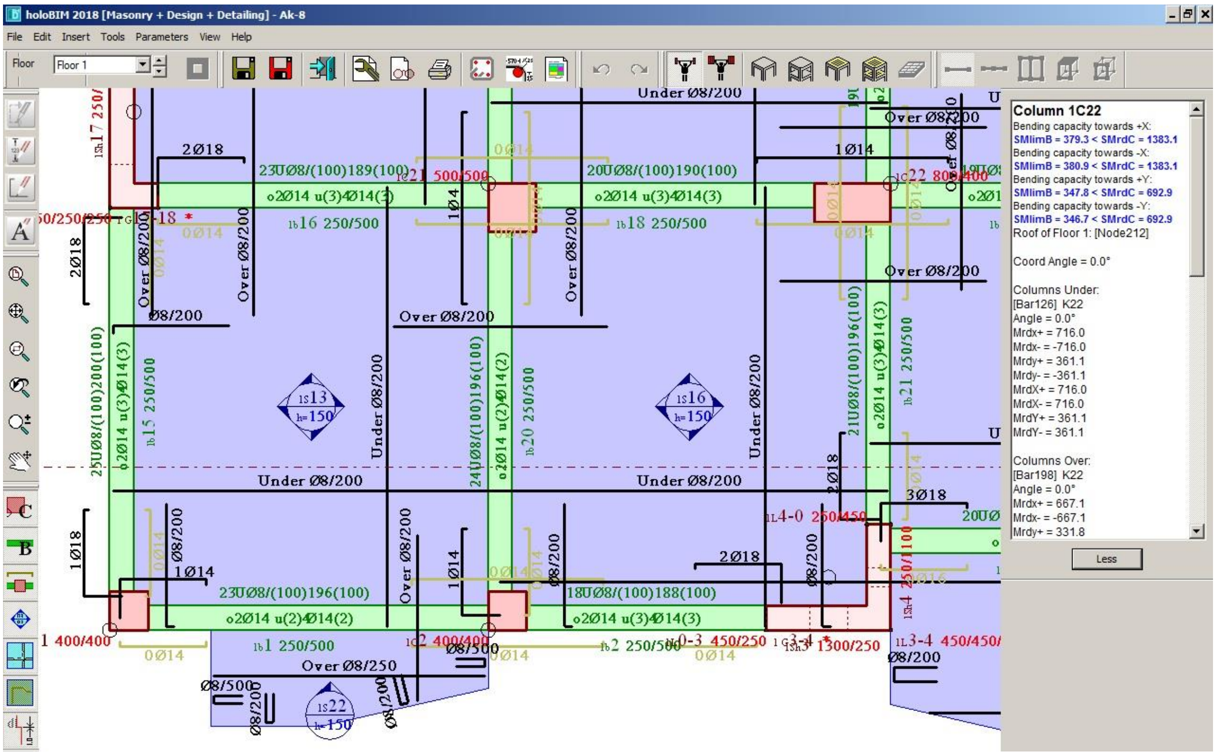
(11) The spherical cursor, both selects the 3D rebar and points to the focus of the stereoscopic projection achieving thus a relaxed stereoscopic observation at a maximum definition.

Important reminder: The display order of the individual results depends on the user's need and is not related to the serial execution of a study because the study has already been completed.

(12) DESIGN OF A COLUMN UNDER BIAXIAL BENDING

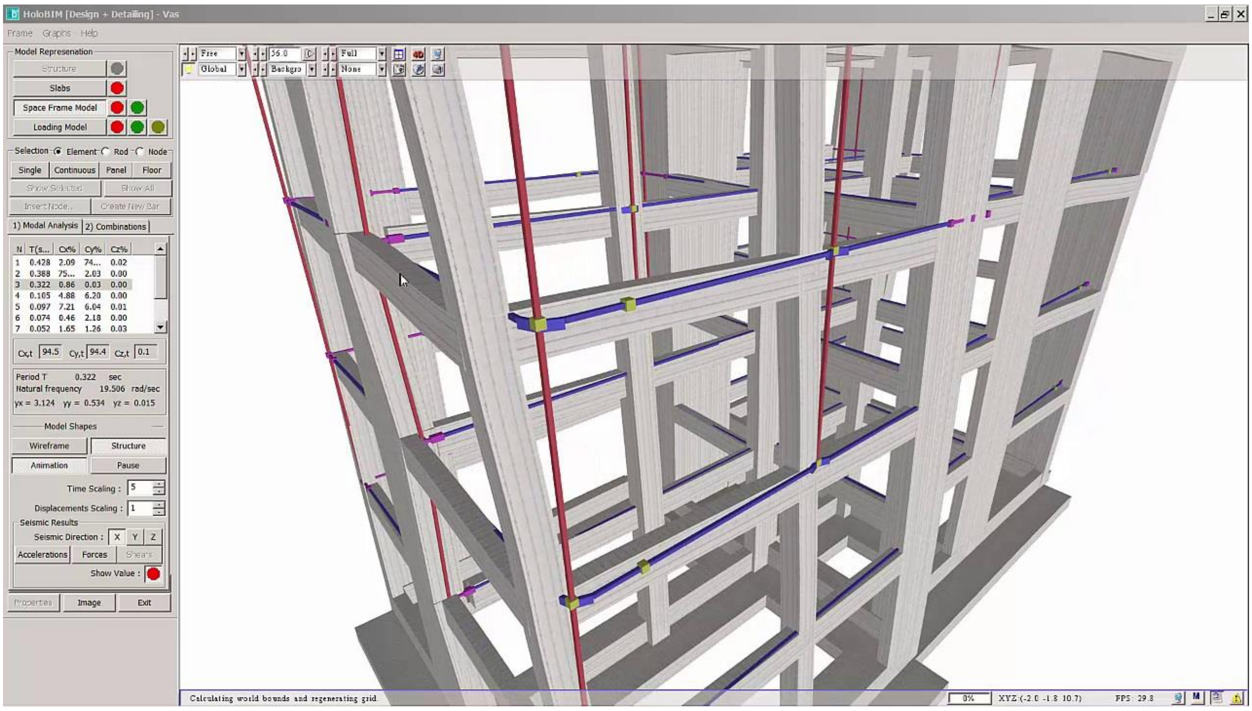


(13) CAPACITY CHECK OF COLUMNS

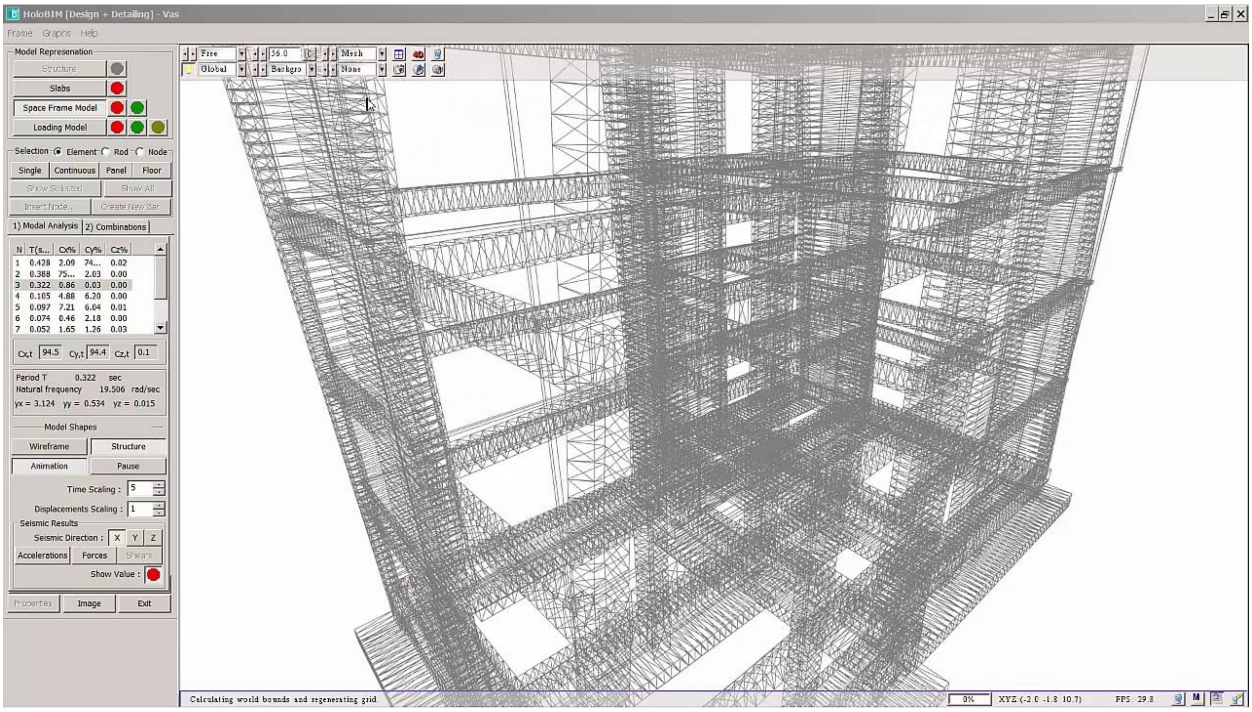


(12) Design under biaxial bending with an accurate definition of the neutral axis and of all the internal stresses.
(13) Column reinforcement increases automatically in order to satisfy bending capacity.

(14) STRUCTURAL FRAME'S TORSIONAL MODE



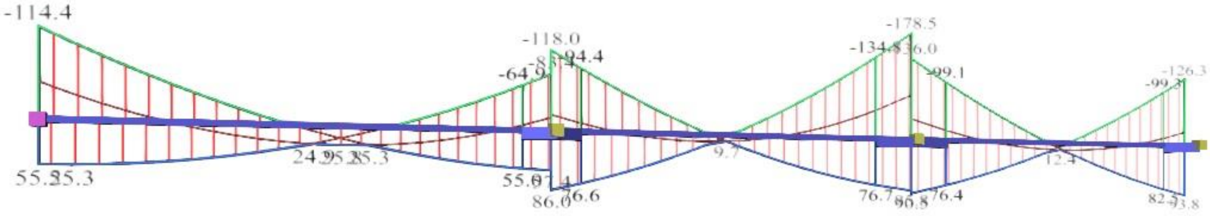
(15) MODELLING OF TORSIONAL MODE



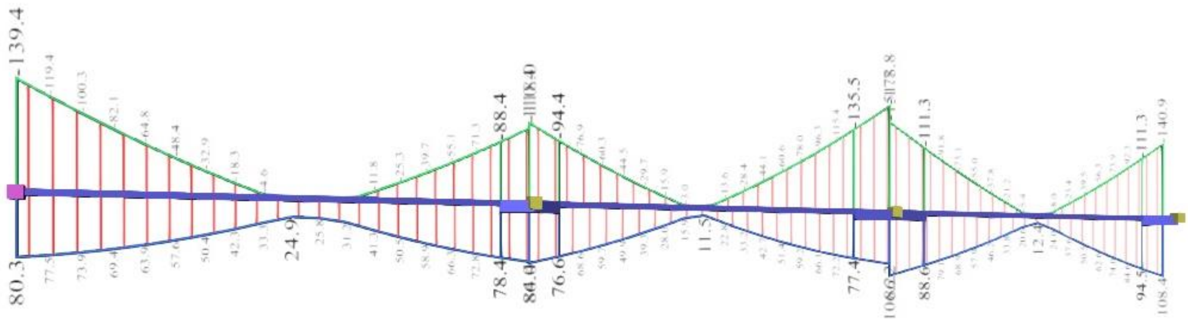
(14) Display of deformed structure may be stereoscopic or not, as shown here, and is rendered 30 times per sec using embedded Virtual Reality Technology.

(15)To achieve this, the structural frame has been modelled using 420,000 triangles and every 1/30 sec the exact coordinates of each triangle vertices are calculated.

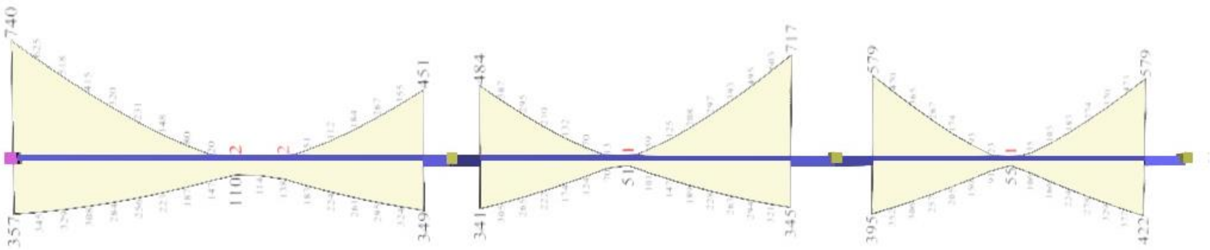
(16) BENDING MOMENT DIAGRAM OF A CONTINUOUS BEAM
THREE LOADING CONDITIONS COMBINED



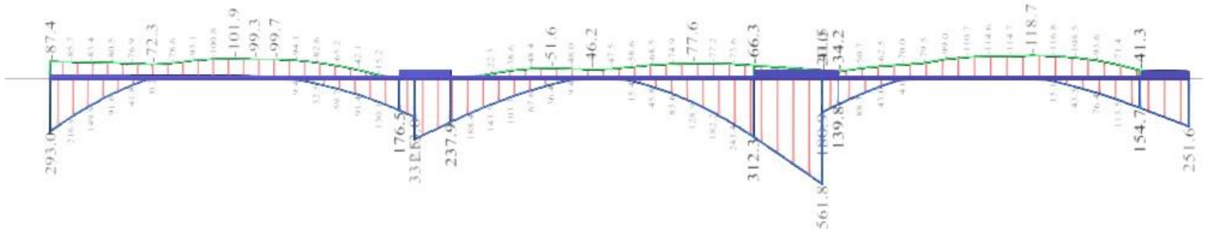
(17) BENDING MOMENT ENVELOPE OF 33 LOADING CONDITIONS COMBINATION



(18) ENVELOPE OF REQUIRED BENDING REINFORCEMENT



(19) BENDING MOMENT ENVELOPE OF THE CORRESPONDING SPREAD FOOTING

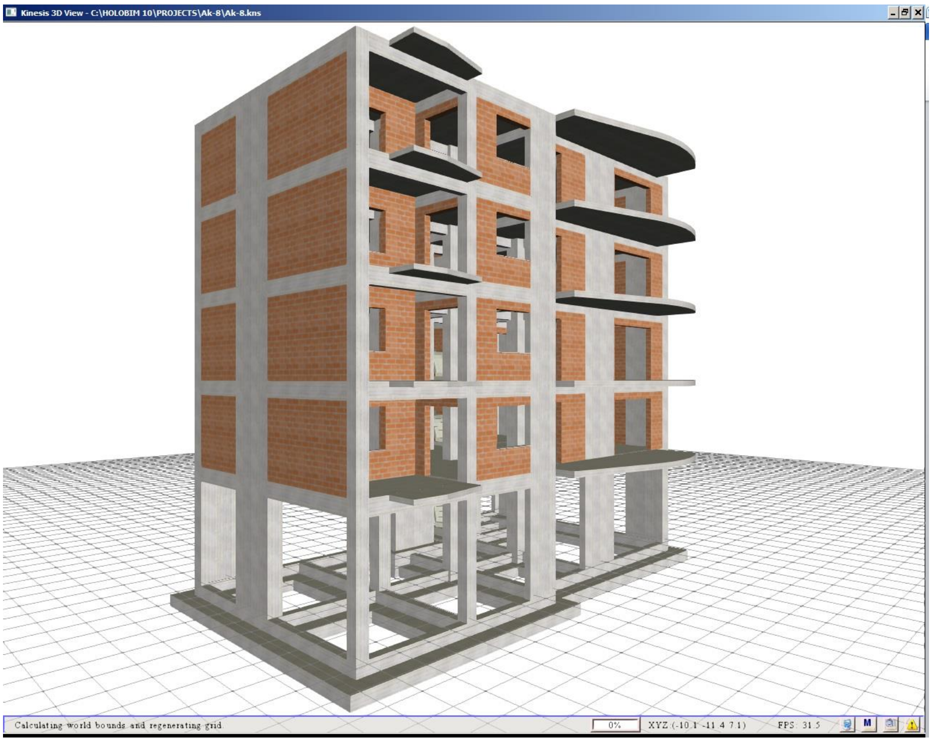


(16) The three combinations: 1.35G+1.50Q, 1.00G+0.30Q+1.00Ex, 1.00G+0.30Q-1.00Ex

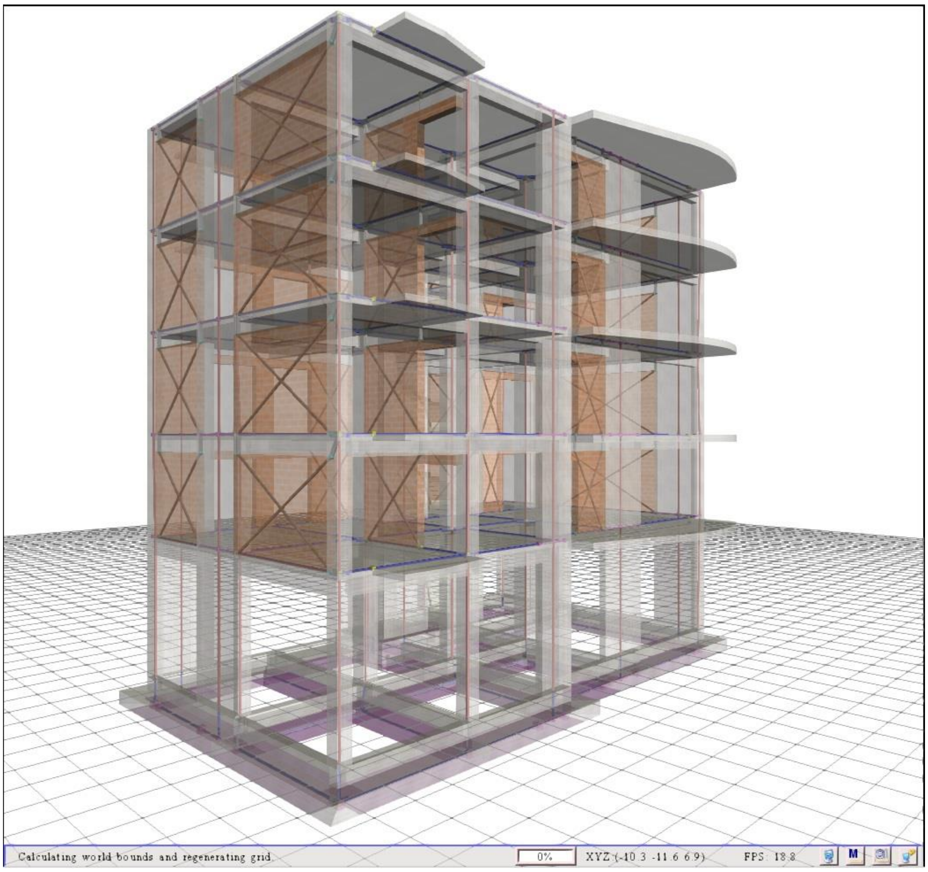
(17) The moment envelope for combination 1.35G+1.50Q and the 32 seismic combinations.

(17), (18), (19) Values are provided in 0.20m intervals since the design and detailing will be based on these values.

(20) INPUT OF MASONRY FOR THE CALCULATION OF STRENGTH



(21) MODELLING OF THE STRUCTURAL FRAME AND MASONRY WALL INFILLS



(21) Optional modelling of masonry with a couple of diagonal bar elements. In each loading condition, only the bar element under compression is taken into account

Appendix II Epilogue

The images shown in the previous pages contain a huge number of equations, stresses and strains, dimensioning and cost elements. The work of the practitioner in the near future will be the evaluation of such images. In the past, engineers consumed all their working time solving the “equations”, dimensioning, drafting the drawings one by one and draw up endless lists of materials under the stress of the timely delivery of the studies, that moreover, were of lower precision and always contained an almost certain probability of errors. Nowadays, the job of engineers is to use all their theoretical training and spend their time analyzing and composing such images that will provide the structures they study and construct with safety, durability and economy.

In a sense, we could say that much of the work of today's practitioners is the so-called 'continuous and continuing education'.

This can be confirmed by the author of this article who has greatly expanded his level of knowledge by creating the HoloBIM ™ software and utilizing its unlimited outputs.

Of course, until now we have talked mainly about the engineer who carries out the design analysis, the engineer that carries out the detailed design and the construction engineer. We have not addressed the concrete industry, the rebar industry and the formwork industry.

The BIM concept and Artificial Intelligence technology ensure that the industry gets what it has always needed i.e. accurate and reliable detailed design. The industry welcomes to have the same data as the designer, to monitor on-line the construction of the project and to plan its own contribution to the project.

The technology of BIM concept and Artificial Intelligence benefits the engineer, the contractor, the industry and especially the owner of the building.

Check the links here below to watch more HoloBIM™ outputs:

- *30 stereoscopic construction details (red/blue glasses are needed): http://www.buildinghow.com/en-us/Store/3D-Booklet*
- *For free training material: http://www.buildinghow.com/en-us/Products/Books*