AHP and Multi-Voting Approaches for Conceptual Design of New Detectors: The Crystal Eye Case Study

F. Renno, F. Barbato, G. Barbarino, F. Guarino, R. Guida and S. Papa

***Abstract*— Main target of this paper is to describe the conceptual design and the virtual prototyping phases of a new detector, named *Crystal Eye*, aimed at the exploration of the electromagnetic counterpart of the gravitational wave events. Such events generated by neutron stars collision (or mergers) are associated with γ-ray bursts. With its characteristics, *Crystal Eye* will provide the continuous exploration and monitoring of the Universe after a Gravitational Wave event with a better resolution than that of other detectors such as the *Fermi Gamma-ray Burst Monitor* (GBM). Thanks to its large field of view and its design, it has the potentiality to be the trigger for those present X-ray astronomy missions (*Chandra, Swift, Integral XMM Newton*) that are based on high angular resolution pointing experiment but that have unfortunately a very small field of view. An intense brainstorming phase, involving a team of physicians and engineers for the generation of concepts, started the design process. So, many preliminary sketches and CAD models were realized to well identify the main requirements of the new detector. Afterwards, considering the features and the constraints of the project, a refinement of the possible solutions among all the alternatives thought was performed, and three virtual prototypes were selected according to the *Multi-Voting Method*. Lastly, the AHP (*Analytic Hierarchy Process*) Multi Criteria decision making approach was considered to designate the best concept.**

***Index Terms*— AHP, Multi-Voting method, Concept Design, Mechanical Design, Detector, Gravitational Wave, X-rays**

I. INTRODUCTION

A long-standing astrophysical paradigm is that collisions, or mergers, of two neutron stars create highly relativistic and collimated jets that power γ-ray bursts of short duration [1], [2], [3]. The observational support for this model, however, was only indirect until August 2017, when the X-ray counterpart associated with the gravitational-wave event GW170817 [4] was observed. The hitherto outstanding prediction that gravitational-wave events from such mergers should be associated with γ-ray bursts, and that a majority of these bursts should be seen off-axis (i.e. they should point away from Earth) was therefore verified. In coincidence with this event, scientists performed observations at X-ray and, later, radio frequencies that result to be consistent with a short γ-ray burst viewed off-axis. The detection of X-ray emission at a location coincident with the kilonova transient provides the missing observational link between short γ-ray bursts and gravitational waves from neutron-star mergers and gives independent confirmation of the collimated nature of the γ-ray burst emission. It results clear from the last observations that this is a new era for the observation of the Universe and all the best and most elastic instruments are needed in order to observe even when and where nothing is expected.

The main currently active experiments in orbit able to observe the gamma and X-ray range are *Chandra*, *XMM-Newton* and *Fermi*. Despite their detection capability and their major observations, they belong to an old concept of sky observatories. *Chandra* and *XMM-Newton'* main limitation, as well as their advantage, is the small angle of view. This characteristic from one side allows to point a source and to obtain a good imaging of that, on the other side limits the exploration of the Universe to a very small portion. On the other side, the localization made by the Fermi γ-ray burst monitor instrument (*Fermi-GBM*) on the FERMI satellite is not very accurate because it is designed to be a wide sight experiment [5].

So, an improved and more performant detector is needed. Nowadays, there are many tools that can be used to make increasingly reliable and optimized products. They can be hardware (i.e. 3D Printers or Turning and Milling Machine for manufacturing) and software (CAD, CAE, CFD) for the realization of *Digital Mock-Ups* (DMU), i.e. digital models of real objects in virtual environments for testing purposes. Thanks to the advantages that can be obtained from the use of the *Virtual Prototyping* (VP) techniques, they are used in a large number of cases, from educational to computer graphics (videogames and renderings), from industrial (i.e. aerospace, mechanics, mechatronics, *etc.*) to medical fields [6], [7], [8], [9], [10]. For instance, referring to the last years, there is a growing interest in their use in the nuclear fusion field [11], [12], [13], [14], [15]. So, the VP techniques, thanks also to the recent and relevant use of the *Reverse Engineering* and *Rapid Prototyping* systems (3D

Manuscript received September 5, 2019; revised March 01, 2020. This work was carried out in the frame of Programme STAR, financially supported by UniNA and Compagnia di San Paolo.

F. Renno is with the Fraunhofer JL Ideas-Dept. of Industrial Engineering, University of Naples Federico II, Italy, (corresponding author, phone: +390817682459; fax: +390817682466; e-mail: fabrenno@unina.it).

F. Barbato is with Department of Physics, University of Naples Federico II, Naples, Italy (felicia.barbato@unina.it).

G. Barbarino is with Department of Physics, University of Naples Federico II, Naples, Italy (giancarlo.barbarino@unina.it).

F. Guarino is with Department of Physics, University of Naples Federico II, Naples, Italy (fausto.guarino@unina.it).

R. Guida is with the Fraunhofer JL Ideas-Dept. of Industrial Engineering, University of Naples Federico II, Naples, 80125, Italy, (riccardo.guida@euroavia.eu).

S. Papa is with the Fraunhofer JL Ideas-Dept. of Industrial Engineering, University of Naples Federico II, 80125, Italy, (stefpapa@unina.it).

scanning and 3D printers), are very helpful for the study of the manufacturability of new devices and for the creation of digital models (for mechanical simulations) and of *Physical Mock-Ups* [16, 17, 18], [19].

Moreover, it is possible to apply many methods to improve the quality of the result as for instance *Brainstorming, Brainwriting, TRIZ, AHP, QFD, Pugh Matrix, etc*. A *Design Method* is a specific procedure used to create a new product foreseeing, analyzing and avoiding numerous adverse phenomena that can have impact on it. So, the design process can be enriched with experiences gained at various stages during its execution and completion providing the basis for subsequent steps. The method consists of multiple interconnecting steps and auxiliary stages but can vary depending on individual situations [20]. So, it is a structured technique that guide and help the designer to get the best results reducing errors, waste of money and unplanned events like failures. In literature there are several researches aimed at classifying the concept generation and design methods based on common features. For instance, in [21] more than 170 methods are listed and organized in cluster considering their similarities and their differences. In addition, if the process is related to innovative products, the designer can develop a new and customized approach mixing different methods to obtain results optimized and expressively focused on his case study [22], [23], [24].

II. CRYSTAL EYE

The *Crystal Eye* will be a modern version of the *Fermi-GBM* detector, designed for a mission on the *International Space Station (ISS)*. Main aim is to improve the localization capability of the GRBs by enhancing the spatial resolution of the monitor with a low-cost mission. The compactness (to be portable by an astronaut during a flight) and the wide field of view with small pixels (to improve the localization of the sources) are the requirements selected in order to make this project competitive.

The *Crystal Eye* objectives will be:

--to alert the community about events containing X-rays and low energy γ-rays,
--to monitor long-term variabilities of X-ray sources,
--to stimulate multi-wavelength observations of variable objects,
--to observe diffuse cosmic X-ray emissions.

The *Crystal Eye* will then be the most performant X and gamma-ray all sky monitor.

A. *Layout, requirements and constraints*

The device proposed is a semi sphere which consists of a double layer of LYSO pixels (about 110 per layer) covered with a veto dome. Each one includes a hexagonal pyramid of LYSO read by adequate *Silicon Photomultiplier* (*SiPM*) matrices. Each pixel should be preferably characterized by hexagonal top and bottom surfaces with diagonal lower than the GBM pixel and, so, about 20-30 mm. Therefore, *Crystal Eye* will be a multilevel structure characterized by pixels on two scintillators layer designed to observe the down-going X and γ-rays and to reject the up-going ones. Thanks to their thickness, the down-going X or gamma ray will give a signal only in the upper pixel, while the up-going will give signal only in the lower one. The smaller size and the larger number of contiguous pixels will improve the spatial resolution and, consequently, the localization of the source. The external dome veto will allow the rejection of the charged particles crossing the detector. It will be made by a scintillator material with a dig, where an optical fiber will guide the collected light to the *SiPMs*. The dome, used in anticoincidence with the crystals, will work as veto for the charged particles. It is made of a plastic scintillator in order to be transparent to both down-going X and gamma rays. The wiring will be placed between the pixel layers and an adequate insulation. Fig. 1 shows the preliminary layout of the *Crystal Eye* detector.

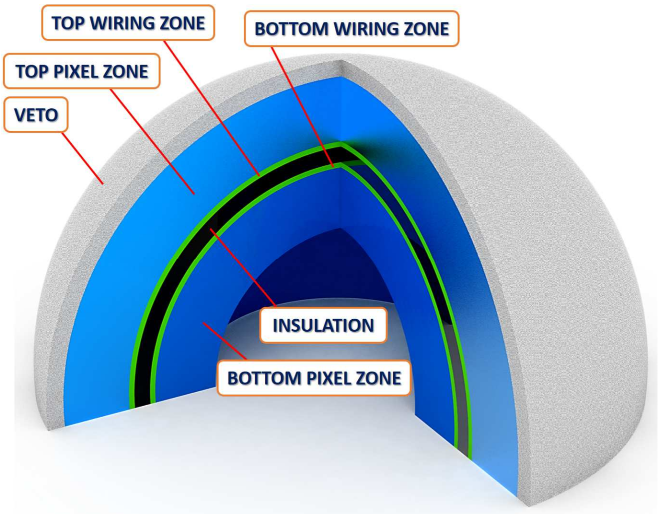


Fig. 1. Preliminary layout of the *Crystal Eye* detector.

III. DESIGN METHODS

A. *Design Process and Concept Generation*

A *Concept* is an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the requirements set for the project. A concept is usually expressed as a sketch or as a rough three-dimensional model [22]. Usually, the team involved in the *Design Process* will realize hundreds of concepts. Moreover, from 5 to 20% of the idea generated will meet the requirements set and will be seriously considered during the *concept selection* phase.

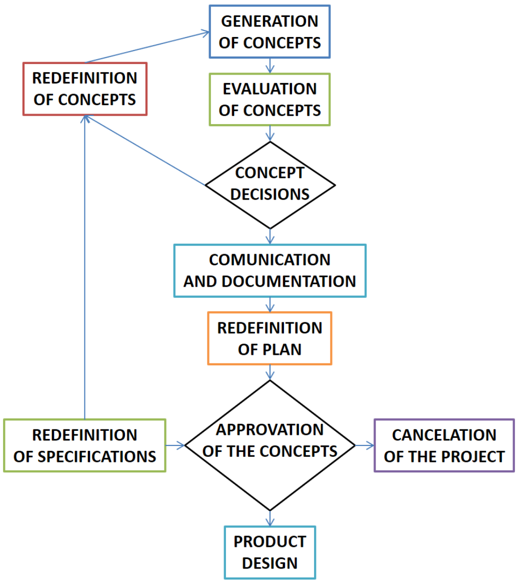


Fig. 2. Conceptual Design of the *Design Process*.

In Fig. 2 the flow diagram of a typical *Design Process* is shown. It was followed for the *Crystal Eye* project. So, an intense brainstorming phase involving a team of physicians and engineers for the *Concept Generation* phase started the *Design Process*. Therefore, many preliminary sketches and virtual prototypes were conceived to well identify the main requirements of the new detector. Fifteen CAD models were realized and classified considering their main characteristics (Fig. 3). Most of them were obtained by means of 3D CAD parametric software following the *Top-Down* approach in order to have full control on the whole geometry and the possibility to modify it quickly and in real time. Some others were realized thanks to a non-parametric approach that made it easier to build polyhedrons, freeform shapes and surfaces. They were designed and ordered in five groups (Fig. 3 - I, II, III, IV, V rows) based on different characteristics. First aim was to investigate on numerous alternatives and identify their main features to then select the best ones. Several geometrical sets, features and parameters were defined. The models depicted on the first row of the Fig. 3 (I group) were thought considering a cylindrical shape (*A*) and a spherical zone (*B* and *C*). On the contrary, the other rows contain different solutions based on spherical shapes. There is an exception for the *H* and *I* models that were realized starting from a polygonal base and planar surfaces to avoid the distortions related to the curvature of the semi sphere. The *D*, *E* and *F* shapes were created considering square pixels to think alternative forms for the detection phase. The *J*, *K* and *L* prototypes were studied to increase the (lateral) zones to be used for wiring, cabling and electronic devices needed for the signal acquisition. The *M* model was thought to maximize the number of hexagons (pixels). On the contrary, the *G*, *N* and *O* models were designed to have fewer hexagons (characterized by the same dimensions) but better located and ordered.

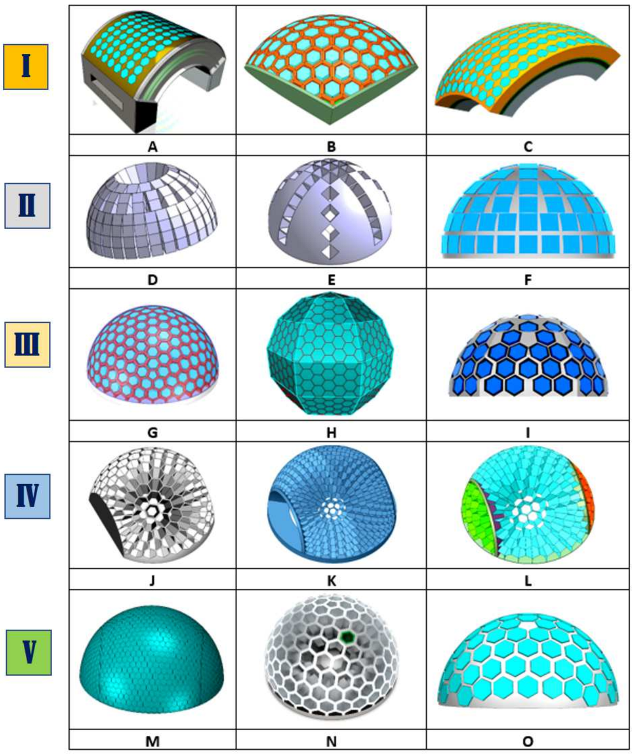
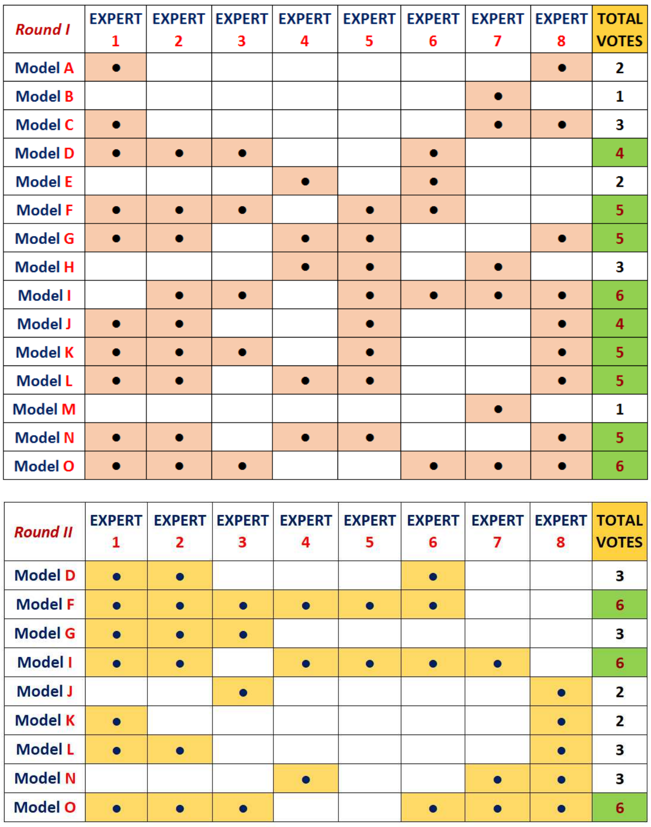


Fig. 3. CAD models.

B. Concept Evaluation and Selection

After the *Brainstorming* and *Concept Generation* phases, the refinement of the possible solutions among all the alternatives thought was needed and so performed. The *Multi-Voting Method* was adapted and used for the *Crystal Eye* project. It is a structured series of votes by a team of experts. It is important to notice that it will not help the group make a single decision but can help narrow a long list of ideas into a manageable number that can be then studied and discussed [26]. Each person votes for as many items as desired, but only once per item. The items with fewer votes (≤ 3 for a 6-10 elements group) are eliminated. Participants go on voting and narrowing the options until there is an appropriate number of ideas to analyze.

Then, in the second round, each person votes for a number of items equal to a minor part of the total number of the starting ideas, again only once per item. The process is stopped when the list is reduced between three to five items, which can be further analyzed [26]. The experts (eight persons) involved in the project were listed on the first row of a table whereas all the options on the first column. In Fig. 4 the results of the two-rounds vote carried out are shown.



Round I	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4	EXPERT 5	EXPERT 6	EXPERT 7	EXPERT 8	TOTAL VOTES
Model A	●							●	2
Model B							●		1
Model C	●						●	●	3
Model D	●	●	●			●			4
Model E				●		●			2
Model F	●	●	●		●	●			5
Model G	●	●		●	●			●	5
Model H				●	●		●		3
Model I		●	●		●	●	●	●	6
Model J	●	●			●			●	4
Model K	●	●	●		●			●	5
Model L	●	●		●	●			●	5
Model M							●		1
Model N	●	●		●	●			●	5
Model O	●	●	●			●	●	●	6

Round II	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4	EXPERT 5	EXPERT 6	EXPERT 7	EXPERT 8	TOTAL VOTES
Model D	●	●				●			3
Model F	●	●	●	●	●	●			6
Model G	●	●	●						3
Model I	●	●		●	●	●	●		6
Model J			●					●	2
Model K	●							●	2
Model L	●	●						●	3
Model N				●			●	●	3
Model O	●	●	●			●	●	●	6

Fig. 4. Results of the *two-rounds vote* according to the *Multi-Voting method*.

In the first round the *D, F, G, I, J, K, L, N, O models* got at least four votes and they were used for the next step of the process. In the second round the *F, I, O models* got six votes and so they were considered the three alternatives for a deeper and more detailed analysis. They were named *Model 1, Model 2* and *Model 3* respectively. The genesis and the main features of these alternative solutions will be described in the next sections.

IV. THREE ALTERNATIVE MODELS

All the models were conceived starting from a specific list of requirements defined during the first phases of the *Design Process*. They are: a) *Symmetry* of the pixels with respect to the zenith, b) maximum *Available Surface* (top face of the pixels), c) adequate *Number of Pixels*, d) assigned *Pixel Shape*, e) assigned *Field of View*, f) regularity of the placement of the pixels, g) minimum extension of the *Not Used Zone*.

As defined in the previous sections, one of the main requirements of the project was the need of a spherical frame. Moreover, another preferable requisite was the hexagonal shape of the top and bottom faces of the pixels. These aspects represented a problem to solve because, as the Swiss mathematician *Leonard Euler* demonstrated, it is not possible to build a closed surface with only regular and equal hexagons. It can happen only on planar surfaces. On the contrary, irregular hexagons can cover a curved surface. An alternative solution for the case study could be provided by the truncated icosahedron (an Archimedean solid made of twelve pentagons and twenty hexagons) as happens for the soccer ball [27], but unfortunately, some requirements were not satisfied.

For these reasons, three different approaches were followed for the *Crystal Eye* project in order to solve the problem and simplify the parametric CAD modeling of the new device. Firstly, a square shape for the top and bottom faces of the pixels, and their placements on the sphere, was considered (*Model 1*). Secondly, a hexagon shape was used on planar surfaces obtained from a solid that approximated the sphere (blue color spherical surface in Fig. 5) with a polyhedron starting from a base with a decagon shape (green color surface in Fig. 5). In this way, it was possible to have the planar surfaces filled with regular hexagons (*Model 2*). Lastly, the third model was obtained building a regular hexagonal mesh with some pentagons and adequate gaps among each hexagonal pixel location, providing a suitable symmetry for all the elements of the device.

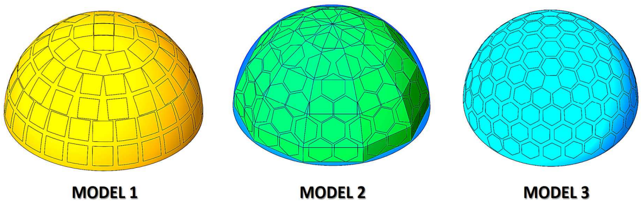


Fig. 5. Layouts of the three selected concepts.

A. *Model 1*

The first concept was based on a semi sphere, in which the cases for the crystals were obtained by rotating the crystal itself. Five pixels were built along a circumferential arc placed in the YZ datum, then each one was rotated of a different quantity around Z-axis, to avoid the permeation of the crystals placed side by side. The top part of the semi sphere was filled in a similar way, placing the last pixel with his axis in correspondence with the vertical axis. The crystals' bases are square-shaped for two reasons: first of all, it allowed to design the model in a simpler and faster way; then, by means of a different configuration of the pixel, it was possible to study if, applying this change to the detector and influencing important parameters such as *Field of View* or distribution of non-active surfaces, there would have been improvement on the performance of the experiment (Fig. 6). The main advantage of the *Model 1* is the symmetrical arrangement of the pixels around the vertical axis (of the local reference system); this feature is a direct result of the way the model was obtained, and that was so developed to comply with one of the main characteristic required by the scientific working principle of the experiment.

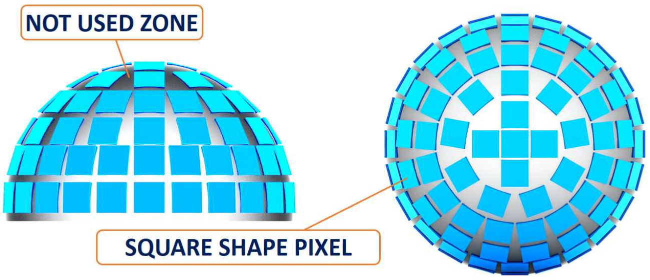


Fig. 6. *Model 1* concept.

B. *Model 2*

The *Model 2* came from the approximation of the semi sphere with a polygonal mesh of ten edges on the equator. The main characteristic is its generation by the repetition of one segment, made of planes, in a circular pattern, that facilitate the management of the hexagons placement. In this way, it was possible to have ten separate and modular sectors (shown with different colors in Fig. 7) easily to be assembled and disassembled. Furthermore, the significant advantage is the planarity of the faces, which avoids the distortion of the edges typical of the spherical shape.

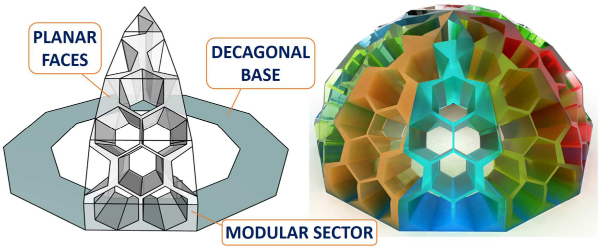


Fig. 7. Modular frame of the *Model 2* concept.

The main drawback is the interpenetration of the prisms in correspondence of two adjacent faces due to the non-gradual alignment of their axis to the center (as instead happens in the case of the spherical shape). This can be solved by means of the management of the spaces among the hexagons remaining in the allowed gap (Fig. 8). The *Model 2* was realized following a non-parametric approach that facilitate the use of surfaces and polyhedrons in the CAD environment. Starting point was a semi sphere with a 127 mm radius with 85 pixel per layer. The gap between the pixel and its place is about 2 mm to allow an analysis on the available space for wiring or insulation zones.

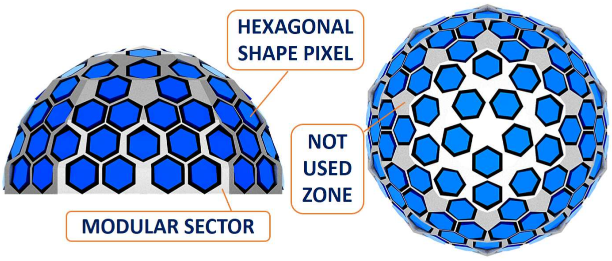


Fig. 8. *Model 2* concept.

C. *Model 3*

The *Model 3* was realized starting from a semi sphere with a 140 mm radius. The location of the pixels was defined by means of a regular polygonal mesh with 112 hexagons and four pentagons assuring the symmetry with respect to the zenith (Fig. 9). Furthermore, it was realized with a full parametric approach and so it is possible to modify each feature of the virtual prototype in real time.

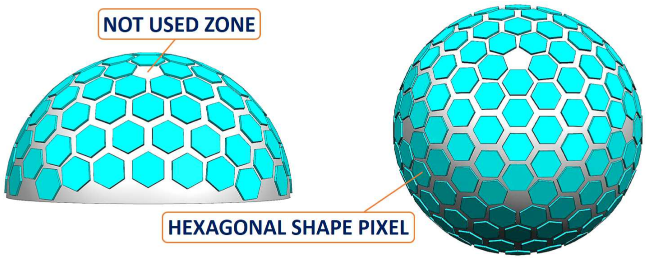


Fig. 9. *Model 3* concept.

Once that the three most voted models were selected, it was needed to choose the best one according to the specific list of requirements previously defined. So, a *Design Review* was set to present and describe all the solutions to the team of experts.

V. AHP

Multicriteria Decision Processes allow to analyze problems that are influenced by several factors and criteria, with the aim of complying in the best way with the greatest number of objectives determined by the requirements of the project. The *Analytic Hierarchy Process* (AHP) is a method that supports multicriteria decision making, developed by *Prof. Thomas L. Saaty* in the '70s, and that is often used in group decision making [28]. AHP is based on the definition of factors that are important for the decision, that are subsequently arranged in a hierarchic structure; inputs of this method can be actual measurements, but also subjective opinions, that allow to manage a wide variety of problems. The first step consists of defining hierarchies that rule the distribution of proprieties among all the elements that are considered in the analysis; for each single element the way it relates to all the others is to be determined. The main objective, called goal, that is connected to a set of criteria is placed at the top of the scale; such criteria can be divided into sets of sub-criteria, used for the following analysis. The next step is to realize a pairwise comparison, in which two homogeneous elements at a time are judged to determinate which one is more important than the other, in order to reach the prefixed goal. Moreover, a numerical scale is necessary to point out how many times such element is more or less important. The outcome of the comparison allows to create a square matrix in which the relative weights are stored [28]. Every evaluator estimates the importance of each element in a subjective way, so during the judgments some small inconsistencies are often generated; these inconsistencies are allowed by the *Analytical Hierarchy Process*, and can be evaluated by means of the so-called *Consistency Ratio* (CR) test, defined as follows:

$$CR = \frac{CI}{RI}$$

CI is the *Consistency Index*, that can be evaluated with the next formula:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where λ_{max} is the principal eigenvalue of the matrix of weights, and *n* is its dimension. *RI* stands for *Random Index*, that is the *Consistency Index* computed when the matrix of weights is filled with random values. *CI* will be equal to 0 if the evaluators take perfectly consistent decisions, but in real cases that value is expected to be less than 0.1, so that the results from AHP analysis can be perceived as reliable [28].

A. *Case Study*

The *Analytic Hierarchy Process* was adopted for an objective evaluation of the different concepts of the *Crystal Eye* project. An extensive analysis was fulfilled to fix the main criterions of the problem:

--*Symmetry of the pixels with respect to the zenith,*
--*Maximum Available surface* (top face of the pixels),
--*Number of Pixels,*
--*Pixels' bases shape,*
--*Field of View,*
--*Pixels' placement regularity,*
--*Minimum Extension of Not-Used Zone.*

Every element was chosen for the scientific requirements of the experiment, whose correct operation depended on a set of different variables. The whole process was divided into two different phases: firstly, each evaluator could compare all the criteria and vote their relative importance, through a pairwise comparison process as seen before. The numerical scale used during this process goes from 1 to 9, following the idea of the *Standard AHP Linear Scale* proposed by *Saaty*.

Table 1
Standard AHP Linear Scale adopted for the case study.

RELEVANCE	DEFINITION	DESCRIPTION
1	EQUAL RELEVANCE	*TWO ACTIVITIES CONTRIBUTE EQUALLY TO THE TARGET*
3	PERCEPTIBLE RELEVANCE OF ONE OVER ANOTHER	*EXPERIENCE AND JUDGMENT SLIGHTLY FAVOR ONE ACTIVITY OVER ANOTHER*
5	ESSENTIAL OR STRONG RELEVANCE	*EXPERIENCE AND JUDGMENT WELL FAVOR ONE ACTIVITY OVER ANOTHER*
7	VERY STRONG RELEVANCE	*THE DOMINANCE OF AN ACTIVITY IS DEMONSTRATED IN PRACTICE*
9	EXTREME RELEVANCE	*THE DOMINANCE OF AN ACTIVITY OVER ANOTHER IS THE HIGHEST POSSIBLE*
2-4-6-8	INTERMEDIATE VALUES BETWEEN TWO CONTIGUOUS EVALUATIONS	*A COMPROMISE IS REQUIRED*

This kind of approach allows to fix the weights that are used in the second part of the process. Then a specific questionnaire is exposed to the experts, that have the chance to decide which model fits the above-mentioned criteria.

The results of the first step of AHP analysis are shown in Fig. 10. The evaluators have chosen the "*Field of View*" and the "*Available Surface of the Pixels*" as the most important elements that should be considered during the next step. Each element will have a variable impact on the result, depending on the value obtained at this stage.

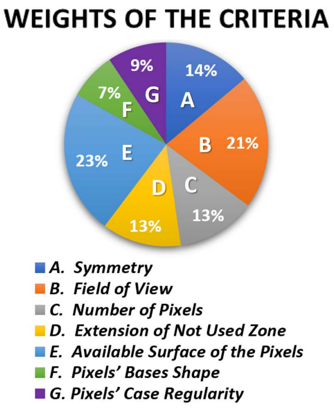


Fig. 10. Weights of the *Criteria*

The second part of the AHP process, that has the aim of identifying the best model out of the three available, has the following outcome: each bar represents the satisfaction of each one of the above-mentioned criteria, gathered for the developed concepts; the longer the bars are, the better the model is, compared to the characteristics required (Fig. 11).

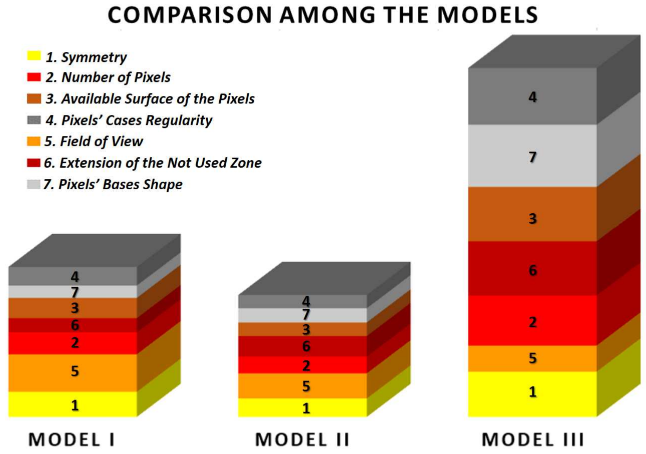


Fig. 11. Global Priorities.

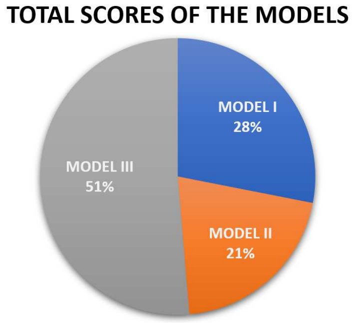


Fig. 12. Total scores of the models.

As evident from the last two figures, the Model III was the concept that definitely fitted for all the requirements, and for this reason was the one to be chosen for the subsequent development of the project (Fig. 12). It is possible to highlight how this concept obtained high scores in all the areas analyzed, determining a clear favourable result.

B. *Comparison among the three alternative solutions*

During the *Design Review*, *Models 1, 2, 3* were analyzed and compared. The corresponding values of the main parameters considered as requirements are reported in Table 2 and Fig. 13. They were used for the *AHP (Analytic Hierarchy Process) Multi Criteria decision making* method to designate the best concept.

TABLE 2
COMPARISON AMONG THE THREE ALTERNATIVE SOLUTIONS.

REQUIREMENTS	MODEL 1	MODEL 2	MODEL 3
AVAILABLE SURFACE (TOP PART)	69.984 mm^2	66.096 mm^2	74.492 mm^2
# PIXELS	96 (x2)	85 (x2)	112 (x2)
PIXEL SHAPE	SQUARE	HEXAGON	HEXAGON
NOT USED ZONE (TOP PART)	86.067 mm^2	30.458 mm^2	43.721 mm^2
(NOT USED ZONE/AVAILABLE SURFACE) RATIO	1,23	0,47	0,59
FIELD OF VIEW	32,740 deg^2	27,316 deg^2	20,355 deg^2

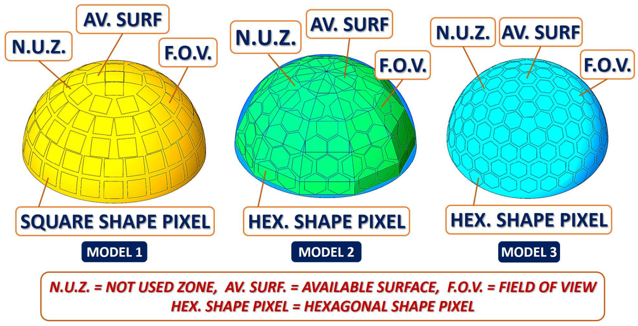


Fig. 13. Comparison among the main parameters of the three models.

So, *Model 1* shows better results in terms of *Field of View* but worse in terms of *Not Used Zone*. *Model 2* has the smallest *Not Used Zone* but less pixels and so *Available Surface*. *Model 3* overcomes the others in terms of *Number of Pixels,* and it means more *Available Surface* for the rays' acquisition.

C. *Results of the use of the AHP method*

At the end of the *Design Process* the selection of the best concept was possible thanks to the AHP approach. The team of experts assigned main importance to the results shown by the *Model 3*. It was accomplished according to the requirements defined during the preliminary steps of the procedure and the *Design Review*. This model was conceived starting from the layout rendered in Fig. 1. So, two layers (gray) of pixels (blue) were realized together with the adequate wiring (green) and insulation zones (black), and with the dome veto (external transparent element) for the rejection of the charged particles crossing the detector (Fig. 14).

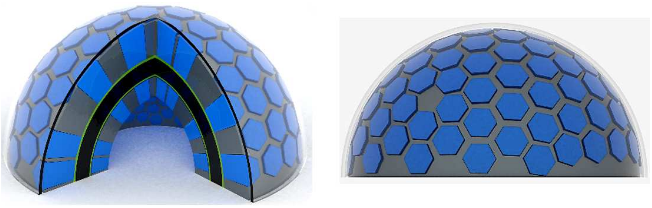


Fig. 14. Best concept model designated by means of the AHP approach.

VI. CONCLUSIONS AND FUTURE WORKS

The conceptual design and the virtual prototyping phases of a new detector, named *Crystal Eye*, aimed at the exploration of the electromagnetic counterpart of the gravitational wave events were described. With its characteristics, *Crystal Eye* will provide the continuous exploration and monitoring of the Universe after a Gravitational Wave event with a better resolution than that of detectors such as the *Fermi Gamma-ray Burst Monitor* (GBM). In order to get the optimal prototype, *the Multi-Voting* and the *AHP* methods were used. So, after an intense brainstorming phase, the generation of concepts and many preliminary sketches and CAD models started the design process. Then, a refinement of the possible solutions among all the alternatives was performed, and three virtual prototypes were selected according to the *Multi-Voting Method*. Lastly, the AHP (*Analytic Hierarchy Process*) *Multi Criteria decision making* approach was used to designate the best concept. In the next months, starting from the optimal concept design voted, the engineering phase will be carried out and the new device will be prototyped by means of 3D printing systems and then tested for the subsequent experiments in orbit.

ACKNOWLEDGMENT

This research was carried out in the frame of *Programme STAR*, financially supported by *UniNA* and *Compagnia di San Paolo*.

REFERENCES

[1] Eichler D., Livio M., Piran T., Schramm D. N., “Nucleosynthesis, neutrino bursts and -rays from coalescing neutron stars”, *Nature,* 340 (6229) (1989), 126-128. DOI:10.1038/340126a0.

[2] Pendleton G. N., Paciesas W. S., Briggs M. S., Preece R. D., Mallozzi R. S., Meegan C. A., Horack J. M., Fishman G. J., Band D. L., Matteson J. L., Skelton R. T., Hakkila J., Ford L. A., Kouveliotou C., Koshut T. M., “The identification of two different spectral types of pulses in gamma-ray bursts”, *The Astrophysical Journal,* 489 (1) (1997), 175-198. DOI:10.1086/304763.

[3] Rezzolla L., Giacomazzo B., Baiotti L., Granot J., Kouveliotou C., Aloy M. A., “The Missing Link: Merging Neutron Stars Naturally Produce Jet-Like Structures and Can Power Short Gamma-Ray Bursts”, *The Astrophysical Journal,* 732 (1) (2011) L6. DOI:10.1088/2041-8205/732/1/l6.

[4] Troja E., Piro L., Eerten H. v., Wollaeger R. T., Im M., Fox O. D., Butler N. R., Cenko S. B., Sakamoto T., Fryer C. L., Ricci R., Lien A., Ryan Jr R. E., Korobkin O., Lee S. K., Burgess J. M., Lee W. H., Watson A. M., Choi C., Covino S., D’Avanzo P., Fontes C. J., Gonzalez J. B., Khandrika H. G., Kim J., Kim S. L., Lee C. U., Lee H. M., Kutyrev A., Lim G., Sanchez-Ramırez R., Veilleux S., Wieringa M. H., Yoon Y., “The x-ray counterpart to the gravitational-wave event gw170817”, *Nature,* 551 (2017) 71 EP.

[5] Abbott B. P. et al., “Multi-messenger observations of a binary neutron star merger”, *The Astrophysical Journal,* 848 (2) (2017) L12. DOI:10.3847/2041-8213/aa91c9.

[6] Lanzotti A., Renno F., Russo M., Russo R., and Terzo M., “Virtual Prototyping of an Automotive Magnetorheological Semi-Active Differential by means of the Reverse Engineering Techniques”, *Engineering Letters,* vol. 23, no. 3, pp115-124, 2015.

[7] Lanzotti, A., Tarallo, A., Carbone, F., Coccorese, D., D’Angelo, R., Di Gironimo, G., Grasso C., Minopoli V., Papa, S., “Interactive Tools for Safety 4.0: Virtual Ergonomics and Serious Games in Tower Automotive”, *Proc. of Congress of the International Ergonomics Association IEA2018,* vol. 822 (pp. 270-280). Springer, Cham, 2018. https://doi.org/10.1007/978-3-319-96077-7_28.

[8] Papa, S., Patalano, S., Lanzotti, A., Gerbino, S., Choley, J.Y., “Towards the integration of thermal physics and geometrical constraints for a 3D-multiphysical sketcher”, *Proc. of 1st IEEE International Symposium on Systems Engineering, ISSE 2015*, 28th-30th September 2015, Rome, Italy, Pages 248-252, ISBN: 978-1-4799-1920-8, DOI: 10.1109/SysEng.2015.7302765.

[9] Vitolo F., Patalano S., Lanzotti A., Timpone F., De Martino M., “Window shape effect in a single Bowden power window system”, *Proc. of 2017 IEEE International Systems Engineering Symposium (ISSE),* pp. 1-5, Vienna 2017. DOI: 10.1109/SysEng.2017.8088308.

[10] Patalano, Vitolo F., Lanzotti, A., “A digital pattern approach to 3D CAD modelling of automotive car door assembly by using directed graphs”, *Mechanisms and Machine Science,* vol. 42 pp. 175-185, 2017, ISBN: 978-3-319-39018-5, DOI: https://doi.org/10.1007/978-3-319-39020-8_13.

[11] Papa, S., Casoria, F., Di Gironimo G., Micciché, G., “Virtual Prototyping and Simulation of Robotic Devices and Maintenance Procedures for Remote Handling Activities in the Access Cell of Dones”, *Proc. of the 26th International Conference on Nuclear Engineering,* ICONE, London 22-26 July, 2018.

[12] Lanzotti A., Renno F., Russo M., Russo R., Terzo M., “A physical prototype of an automotive magnetorheological differential”, *Lecture Notes in Engineering and Computer Science,* Vol. 3 LNECS, pp. 2131-2135. ISBN: 978-988192529-9, 2013.

[13] Di Gironimo G., Carfora D., Esposito G., Lanzotti A., Marzullo D., Siuko M., "Concept design of the DEMO divertor cassette-to-vacuum vessel locking system adopting a Systems Engineering approach", *Fusion Engineering and Design,* Volume 94, Issue 1, 2015, Pages 72-81.

[14] Di Gironimo G., Marzullo D., Mozzillo R., Tarallo A., Villone F., “The DTT device: First wall, vessel and cryostat structures”, *Fusion Engineering and Design,* Vol 122 (2017), pp. 333-340.

[15] Micciché, G., Ascott, M., Bakic, A., Bernardi, D., Breñosa, J., Coloma, S., Crofts, O., Di Gironimo, G., Ferre, M., Fischer, G., Ibarra, A., Karap, A., Gabor Kiss, I., Kunert, C., Lorenzelli, L., Mitchell, G. Mittwollen, M., Pagani, P., Papa, S., Matyas, T., “The Remote Handling System of IFMIF-DONES”, *Fusion Engineering and Design,* Volume 146, September 2019, Pages 2786-2790.

[16] Crescenzi F., Roccella S., Brolatti G., Cao L., Crisanti F., Cucchiaro A., Di Gironimo G., Labate C., Lucca F., Maddaluno G., Ramogida G., Renno F., “Vessel and In-Vessel Components Design Upgrade of the FAST Machine”, *Fusion Engineering and Design,* 88 (9-10), pp. 2048-2051, 2013.

[17] Lanzotti, A., Martorelli, M., Staiano, G., “Understanding process parameter effects of RepRap open-source three-dimensional printers through a design of experiments approach”, *Journal of Manufacturing Science and Engineering, Transactions of the ASME,* 137 (1), 2015.

[18] Humayun K. B., "Automatic Planning for Scanning: Optimizing 3D Laser Scanning Operations Using BIM and TLS", *IAENG International Journal of Computer Science,* Vol. 46, no.3, pp485-493, 2019.

[19] Yi-Cheng Lee, and Syh-Shiuh Yeh, "Using Machine Vision to Develop an On-Machine Thread Measurement System for Computer Numerical Control Lathe Machines," *Lecture Notes in Engineering and Computer Science: Proceedings of The International MultiConference of Engineers and Computer Scientists*, 13-15 March, 2019, Hong Kong, pp67-72.

[20] Gregory, S. A. “The Design Method. Boston”, *Springer US.* ISBN: 9781489961693.

[21] Sakae, Y., Kato, T., Sato, K., & Matsuoka, Y., “Classification of design methods from the viewpoint of design science”, *Proc. of the DESIGN 2016 14th International Design Conference,* DS 84, 493-502, (2016).

[22] Ulrich, K.T., Eppinger, S.D., *“Product Design and Development”* 5th Edition, *McGraw-Hill,* 2012, New York.

[23] Lanzotti A., Carbone F., Grazioso S., Renno F., Staiano M., “A new interactive design approach for concept selection based on expert opinion”, *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Volume 12, Issue 4, 1 November 2018, Pages 1189-1199. https://doi.org/10.1007/s12008-018-0482-8.

[24] Hitoshi Yano, and Rongrong Zhang, "Interactive Decision Making for Multiobjective Fuzzy Random Programming Problems with Simple Recourse through a Fractile Model", *IAENG International Journal of Applied Mathematics*, Vol. 46, no. 3, pp379-387, 2016.

[25] Ullman, D. G., “The mechanical design process”, New York: *McGraw-Hill.* ISBN 9780072975741.

[26] Scholte, P. et al., “The Team Handbook, 3rd Edition”, *Madison, WI: Joiner Associates Inc.*, ISBN: 978-1884731266.

[27] Kotschik D., “The topology and combinatorics of soccer balls”, *American Scientist,* 2006, 94: 350– 357. DOI: 10.1511/2006.60.1001.

[28] Saaty, T. L., “How to make a decision: The analytic hierarchy process”, *European Journal of Operational Research*, Volume 48, Pages 9-26, (1990).