

New Developments of the Computer Aided Analytical Definition of the Map-Wise Calculus Domains

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Abstract. The development of the computer aided analytical models is useful for the knowledge integration process that leads to hybrid models of the complex phenomena. The authors have a long run experience in conceiving original software instruments in mechanical engineering, at present being explored new paradigms. The resulting general concepts may be used to create new software general libraries and, further on, to easily develop new software instruments. From this standpoint, the new general definitions are paramount for the upper level developments. In this way, the general definitions of the calculus domain are tested by implementing the according data processing operations included in the definition-calculus-visualization triad. The calculus domain is divided in polygonal geometrical entities, similar to the LEGO pieces that may be added or extracted. The definition is general because a set of polygons may be used for the approximate discretization of any continuous domain. The computer code developed by us is structured in several header files that may be reused in other projects and the results' accuracy was tested in several case studies. The paper conceived as a progress report also presents the strengths of our approach and the future development directions.

1. Introduction

Development of computer based instruments in research is a long run concern of the authors. Some of our original solutions are related to the processing of the large matrices, [1], software library which was used in the development of various numerical applications (general numerical methods, FEM, FDM that solve structural, heat transfer and fluid dynamics problems), automatic calculus of the stresses using an analytical approach, [2], experimental data reduction in the strain gage technology, [3, 4], and in photoelasticimetry [5]. Computer was identified as the most versatile instrument in obtaining information of synthesis in engineering, [6], and, moreover, in the development of original complex hybrid models, [7], whose components require a high degree of integration. However, the development of computer based research instruments requires a large amount of resources in terms of man-hours. Being acquired an important experience in the development of software solutions for specific engineering research projects, it was expected to occur a new generation of concepts which are based on both the previously mentioned large experience and the latest IT achievements, i.e. new paradigms, new programming languages, new environments and new methods to interface the applications that add an overall synergic effect.

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2. Problem formulation

The effective development of the original software instruments depends on the best ratio between the effort and the quality of the results. We came to the conclusion that the rapid development of the software instruments used to create models is a main goal, in this way being considered a series of objectives, such as: atomization, ‘librarization’, parameterization, automatization and integration, [8].

An important support in the fulfilment of the previously mentioned objectives is to conceive flexible and general definitions, from which the rest of the project may be easily built-up. From this standpoint, a general definition of the calculus domains may be very useful for the rapid development of the particular, upper level applications, [9]. In this way, we considered a general calculus domain that may be defined in two ways. Firstly, the curved boundaries of the domain may be approximated using a set of spline functions. Secondly, the calculus domain may be discretized using polygons which may be considered as ‘puzzle’ pieces that may be added ($Sign=+1$) or taken out of the domain ($Sign=-1$).

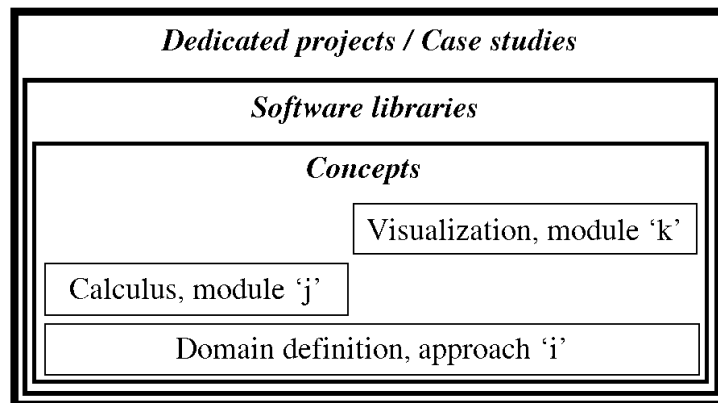


Figure 1. Levels of development in the ‘domain’ wise approach.

The first aim of this definition was the calculus of the geometrical characteristics using analytical approaches. However, there may be solved many other problems that may have domain-related meta information, such as analytical models of the alloy solidification diagrams. The geometrical characteristics’ calculus relations for a particular domain whose boundaries are approximated using spline functions were tested and the results are presented in [10]. The solution based on polygons was also tested for particular shapes of the cross sections and the results are presented in [11].

The calculus domains’ general definition concept was not tested yet using the previously mentioned calculus methods.

3. Discussion

Beside the concepts regarding the general definition and the calculus methods, the paradigm was extended by acknowledging the visualization problems. The true dimension of the development strategy may be noticed in the above figure. The level of the theoretical concepts includes the definition-calculus-visualization triad. Each of these components has several subsequent levels of lower complexity. In this way, when a new solution is designed, the analyst is able to select the most appropriate definition-calculus-visualization combination of methods.

The correctness, the coherence and the effectiveness of the concepts may be verified by implementing and testing them. In order to create reusable computer solutions, the first level of implementation of the concepts is the design of the software basic libraries. An important aspect in this stage is the intelligent design of the data structures that will be used in the upper level of complexity development of the software. In reference [9] are presented only the basic ideas regarding

the structure of files used to define in a general way the calculus domain, not the data structures, this aspect being included in the upper level, i.e. the implementation of the libraries.

3.1. Input data automatically loaded

According to [9] it was supposed that the input data is stored in CSV files. An example regarding the discretization in polygonal subdomains and the according hierarchy of input files is given in the following figure. In comparison with figure 4 of reference [9], we considered that the definition of the connections should also include a flag regarding the visibility of the current segment, as it is presented in column E of the 'S_P_001_2_connections.csv' file presented in the following figure.

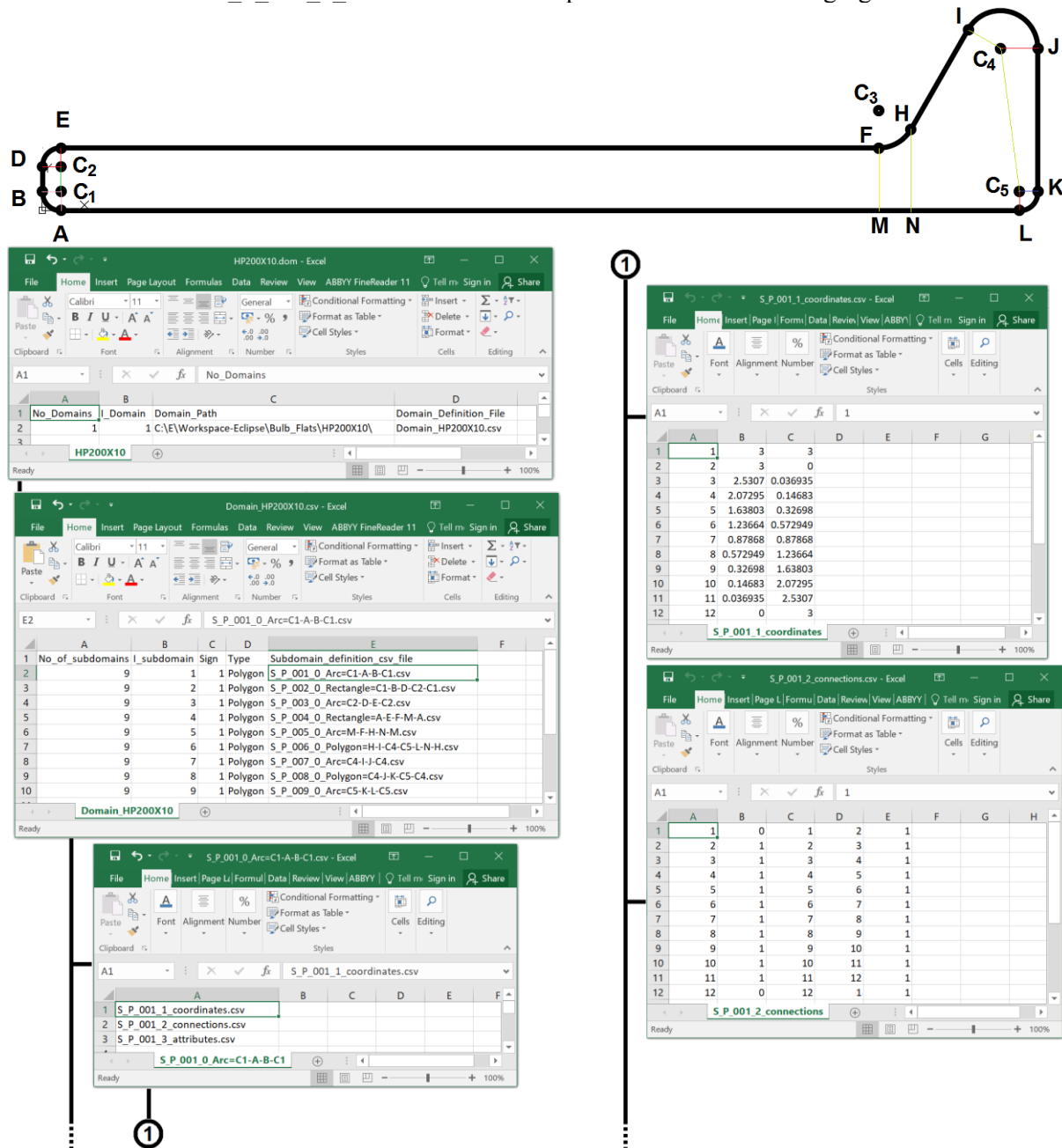
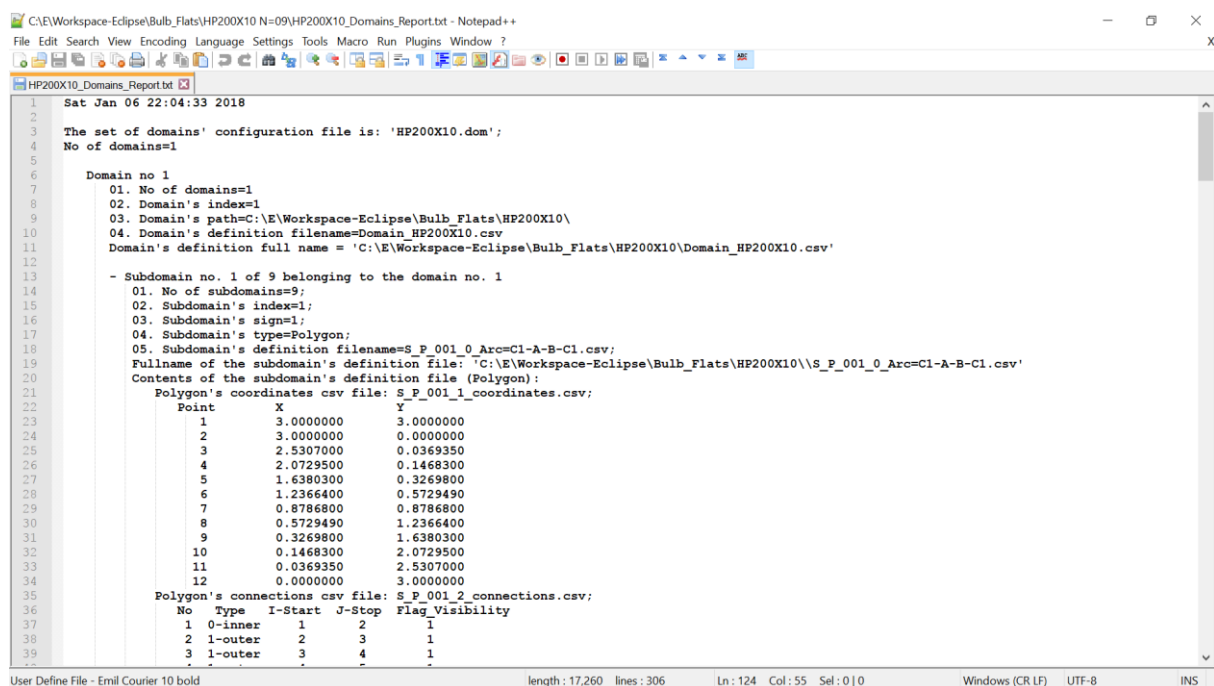


Figure 2. Discretization in subdomains and a part of the input files' structure.

Reading the data from the CSV files is a repetitive operation, therefore it is solved in standalone modules of the program. One can notice that 'HP200X10.dom', 'Domain_HP200X10.csv' and 'S_P_001_0_Arc=C1-A-B-C1.csv' files include alphanumeric information while the 'S_P_001_1_coordinates.csv' and 'S_P_001_2_connections.csv' include numeric information only. The reading operations from the alphanumeric CSV files is solved in the 'load_csv_of_strings.h' header file while the numeric data is read using the 'load_csv_file.h' header. The header files may be reused in the development of other computer codes by simply calling the according function.

3.2. 'Domain' concept related implementations

The definition-calculus-visualization concepts were all implemented as a series of header files. The 'domains_basic_types.h' header is a component of the definition concept and it includes definition of types of variables that are used in the upper level 'domain'-related software.



```

Sat Jan 06 22:04:33 2018
The set of domains' configuration file is: 'HP200X10.dom';
No of domains=1

Domain no 1
01. No of domains=1
02. Domain's index=1
03. Domain's path=C:\E\Workspace-Eclipse\Bulb_Flats\HP200X10\
04. Domain's definition filename=Domain_HP200X10.csv
Domain's definition full name = 'C:\E\Workspace-Eclipse\Bulb_Flats\HP200X10\Domain_HP200X10.csv'

- Subdomain no. 1 of 9 belonging to the domain no. 1
01. No of subdomains=9;
02. Subdomain's index=1;
03. Subdomain's sign=1;
04. Subdomain's type=Polygon;
05. Subdomain's definition filename=S_P_001_0_Arc=C1-A-B-C1.csv;
Fullname of the subdomain's definition file: 'C:\E\Workspace-Eclipse\Bulb_Flats\HP200X10\S_P_001_0_Arc=C1-A-B-C1.csv'
Contents of the subdomain's definition file (Polygon):
Polygon's coordinates csv file: S_P_001_1_coordinates.csv;
    Point      X      Y
    1      3.0000000      3.0000000
    2      3.0000000      0.0000000
    3      2.5307000      0.0369350
    4      2.0729500      0.1468300
    5      1.6380300      0.3269800
    6      1.2366400      0.5729490
    7      0.8786800      0.8786800
    8      0.5729490      1.2366400
    9      0.3269800      1.6380300
    10     0.1468300      2.0729500
    11     0.0369350      2.5307000
    12     0.0000000      3.0000000
Polygon's connections csv file: S_P_001_2_connections.csv;
    No  Type  I-Start  J-Stop  Flag_Visibility
    1  0-inner  1      2      1
    2  1-outer  2      3      1
    3  1-outer  3      4      1
  
```

Figure 3. Domains' input data report file presented in NotePad++.

One of the most important aspects in data computing regards the verification of the correctness of the input data. In this project, the input data is listed in a report text file. The according function was developed in the 'domains_report_info_4_a_set_of_domains.h' header file. An example regarding the contents and the structure of the report file is given in the above figure.

Besides the input analytical data presented as values, there may be also used a visually validation of the data. In this case, there was developed a function which generates AutoCAD script files, i.e. text files which contain AutoCAD commands. There are created several SCR files: one for each polygonal subdomain, one for the entire domain by appending the commands from all the subdomains' SCR files and one for the domain's boundary. All these operations are done by the use of the function included in the 'domains_create_AutoCAD_script_files.h' header. An example regarding the contents of the 'All_Edges.SCR' file of the current domain is given in the following figure. The shaded area includes the AutoCAD commands from the 'S_P_001_0_Arc=C1-A-B-C1.SCR' file which was generated for the first polygonal subdomain. In these 2D drawings, the final line in the SCR files is 'ZOOM EXTENTS'.

```

1 LINE 3.0000000,3.0000000,0 3.0000000,0.0000000,0
2 LINE 3.0000000,0.0000000,0 2.5307000,0.0369350,0
3 LINE 2.5307000,0.0369350,0 2.0729500,0.1468300,0
4 LINE 2.0729500,0.1468300,0 1.6380300,0.3269800,0
5 LINE 1.6380300,0.3269800,0 1.2366400,0.5729490,0
6 LINE 1.2366400,0.5729490,0 0.8786800,0.8786800,0
7 LINE 0.8786800,0.8786800,0 0.5729490,1.2366400,0
8 LINE 0.5729490,1.2366400,0 0.3269800,1.6380300,0
9 LINE 0.3269800,1.6380300,0 0.1468300,2.0729500,0
10 LINE 0.1468300,2.0729500,0 0.0369350,2.5307000,0
11 LINE 0.0369350,2.5307000,0 0.0000000,3.0000000,0
12 LINE 0.0000000,3.0000000,0 3.0000000,3.0000000,0
13 LINE 3.0000000,3.0000000,0 0.0000000,3.0000000,0
14 LINE 0.0000000,3.0000000,0 0.0000000,7.0000000,0
15 LINE 0.0000000,7.0000000,0 3.0000000,7.0000000,0
16 LINE 3.0000000,7.0000000,0 3.0000000,3.0000000,0
17 LINE 3.0000000,7.0000000,0 0.0000000,7.0000000,0
18 LINE 0.0000000,7.0000000,0 0.0369350,7.4693000,0
19 LINE 0.0369350,7.4693000,0 0.1468300,7.9270500,0
20 LINE 0.1468300,7.9270500,0 0.3269800,8.3619700,0
21 LINE 0.3269800,8.3619700,0 0.5729490,8.7633600,0
22 LINE 0.5729490,8.7633600,0 0.8786800,9.1213200,0
23 LINE 0.8786800,9.1213200,0 1.2366400,9.4270500,0
24 LINE 1.2366400,9.4270500,0 1.6380300,9.6730200,0
25 LINE 1.6380300,9.6730200,0 2.0729500,9.8531700,0
26 LINE 2.0729500,9.8531700,0 2.5307000,9.9630700,0
27 LINE 2.5307000,9.9630700,0 3.0000000,10.0000000,0
28 LINE 3.0000000,10.0000000,0 3.0000000,7.0000000,0
29 LINE 3.0000000,0.0000000,0 3.0000000,10.0000000,0
30 LINE 3.0000000,10.0000000,0 166.5970000,10.0000000,0
31 LINE 166.5970000,10.0000000,0 166.5970000,0.0000000,0
32 LINE 166.5970000,0.0000000,0 3.0000000,0.0000000,0
33 LINE 166.5970000,0.0000000,0 166.5970000,10.0000000,0
34 LINE 166.5970000,10.0000000,0 167.4330000,10.0438000,0
35 LINE 167.4330000,10.0438000,0 168.2600000,10.1748000,0

```

Figure 4. The AutoCAD commands stored in a text SCR file.

The results of the AutoCAD SCRIPT command for the ‘_All_Edges.SCR’ file are presented in the following figure, where the subdomains may be noticed. This drawing was used to present the notation of the subdomains in figure 2. There may be noticed that the approximation of the arcs with segments that are chords of angles less than 10° is accurate from a geometrical point of view.

3.3. Results

The calculus of the geometrical characteristics is done by the use of the function developed in the ‘domains_geometrical_characteristics_of_a_domain.h’ header. In order to have a suggestive presentation of the results, the values are presented in a CSV file. In this way, the analyst may use the facilities of a spreadsheet application in order to check the correctness of the results. Moreover, because we already developed functions which read CSV files of alphanumeric or numeric types, these results may be read in upper level applications (for the computation of the geometrical characteristics of larger or more general cross sections and/or for the computation of the stresses) which use these header files.

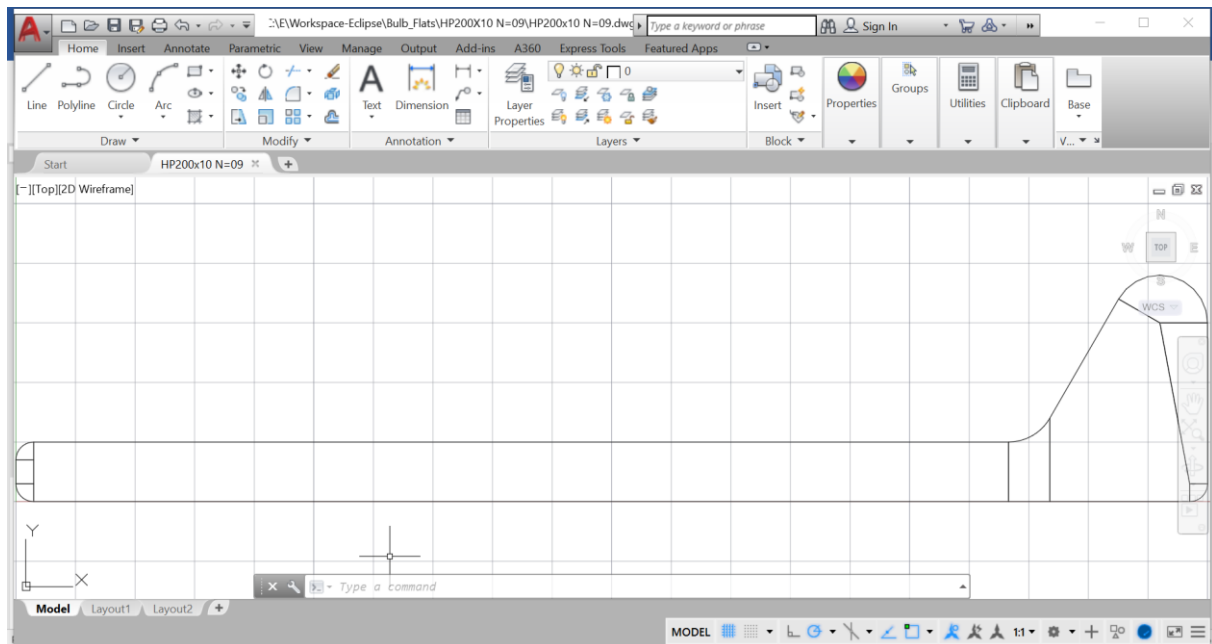


Figure 5. The AutoCAD drawing created by the use of the 'All_Edges.SCR' text file.

As it can be noticed in the following figure all the relevant information, including the data used to identify the subdomain, the subdomain's type and its definition file are presented in the CSV results text file.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Sbd No.	Sbdm_T	Sbdm_De	Sbdm_A	Sbdm_Hoi	Sbdm_Vert_C	Sbdm_Hc	Sbdm_Ve	Sbdm_Hc	Sbdm_Ve	Sbdm_Hoi	Sbdm_Hc	Sbdm_Ve	Sbdm_Hoi	Sbdm_Hc	Sbdm_Ve	Sbdm_Hoi	Sbdm_Hc	Sbdm_Ve	Sbdm_Hoi	Sbdm_Hc
2	9 Polygon	1 C:\E\Worl	7.0396	1.72938	1.72938	12.1741	12.1741	25.4624	25.4624	19.7303	4.4088	4.4088	-1.32329	-6.95054	-117.95	344.49	97939.7	-5772.45			
3	2 9 Polygon	1 C:\E\Worl	12	1.5	5	60	18	316	36	90	16	9	0	-3.67992	-118.18	178.502	167605	-5218.68			
4	3 9 Polygon	1 C:\E\Worl	7.0396	1.72938	8.27062	58.2215	12.1741	485.937	25.4624	102.01	4.40881	4.4088	1.32329	-0.4093	-117.95	5.58811	97939.7	-338.523			
5	4 9 Polygon	1 C:\E\Worl	1636	84.7985	5	8179.85	138728	54532.3	1.54E+07	693639	13633.1	3.65E+06	-1.93E-10	-3.67992	-34.881	35787.1	5.64E+06	-209990			
6	5 9 Polygon	1 C:\E\Worl	77.4	170.252	5.64251	436.731	13177.5	3320.7	2.24E+06	74440.7	856.444	315.44	86.5321	-3.03741	50.5727	1570.53	198274	11975.9			
7	6 9 Polygon	1 C:\E\Worl	581.32	185.237	13.5935	7902.24	107683	150913	2.00E+07	1.47E+06	43493.5	19615.5	2432.79	4.9136	65.5576	57528.7	2.52E+06	-184825			
8	7 9 Polygon	1 C:\E\Worl	82.821	193.013	33.7798	2797.69	15985.6	94848.7	3.09E+06	539797	343.566	1008.44	-191.941	25.0998	73.3336	52521.2	446406	-152638			
9	8 9 Polygon	1 C:\E\Worl	148.5	197.061	18.5455	2754	29263.5	59474.2	5.77E+06	541927	8400.07	523.705	-777.784	9.86553	77.3815	22853.4	889726	-114144			
10	9 9 Polygon	1 C:\E\Worl	7.0392	198.271	1.72941	12.1736	1395.66	25.4617	276724	2415	4.40849	4.40837	1.32332	-6.95051	78.5914	344.469	43482.8	3846.49			
11	Sum suball types all	C:\E\Worl	2559.1	Horiz_C=119.679	Vert_C=8.679	22213.1	306275	363942	4.68E+07	3.32E+06	No summ	No summ	No summ	No summ	No summ	171134	10098600.00	-657104			
12																					

Figure 6. Results are stored in CSV files that may be opened in spreadsheet applications where the calculi may be easily verified.

The values of the geometrical characteristics presented in the above figure were verified using independent sources and the results are accurate. The discretization of an arc in segments that are chords of angles less than 10° is also accurate from the geometrical characteristics' point of view.

3.4. Future development plans

The studies presented so far use the definition of the domains by discretizing them in polygonal subdomains. The calculus branch was developed only for the computation of the geometrical characteristics. The visualisation of the results is done by only by the use of the AutoCAD script files.

All these limitations may be overpassed by the future development of the domains-related implementations.

The definition of the domain may also use ‘simple’ shape geometric entities, such as rectangles, circles, half-circles, quarter-circles and others. The functions already developed in the previously mentioned header files have a flexible structure that allows us to add the necessary sequences specific to a new particular ‘simple’ shape.

The calculus of the geometrical characteristics may be also extended by incorporating the code already developed for the domains bounded by sets of spline functions.

The graphical representation may employ other software libraries (OpenGL) and new algorithms in order to automatically generate the drawings to be used for visual validation or in complex design or research projects.

4. Conclusions

The paper is a progress report of the domains-related concepts previously presented. This follow-up paper presents the latest implementations that are based on the domains’ discretization in polygonal subdomains.

The study presented in the paper has a series of strong points:

1. it is a complete solution, because it includes implementation of the previously mentioned definition-calculus-visualization triad;
2. it offers important facilities regarding the input and output data validation expressed as values and as graphical interpretations of the values that are useful for visual verification;
3. the original application which uses the header files is flexible and it may be connected with upper level applications which may easily load the output information of the current data processing stage;
4. the domains discretized with polygons may be connected with the commercial CAD applications;
5. all the ‘simple’ shape geometrical entities may be approximated using polygons, in this way being possible to virtually define any domain;
6. the accuracy of the results is kept under control by relating it with the finesse of the discretization with polygonal subdomains;
7. the software libraries, programming environment and the editor used in the software development are: MinGW, Eclipse, NotePad++ which may be also found in other operating systems, where Excel may be replaced by Calc, therefore the original software may be considered a cross-platform application.

The ideas and the implementations presented in the paper are useful in the development of a larger project regarding the analytical definition of the ship hull cross sections and, further on, to create a ship strength full analytical model.

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