MECHATRONIC DESIGN
DEVELOPMENT TOOL

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1 INTRODUCTION

To help the development of the tables and the Function-Means tree of the first and second phases of the design process, an excel workbook has been programmed with several macros that aid the design process. The workbook can be downloaded in the education section of the following link:

http://laship.ufsc.br/site/en/

This workbook is compatible with all office versions from 2007. Older versions such as Office 2003 and will not work properly. This workbook should not be opened with Google Sheets and OpenOffice, since the macros and shapes generated by the workbook are not compatible with these platforms.

1.1 The general attributes sheet

When first opening the excel file, a security warning will be displayed (Figure 1-1). Click on enable content.

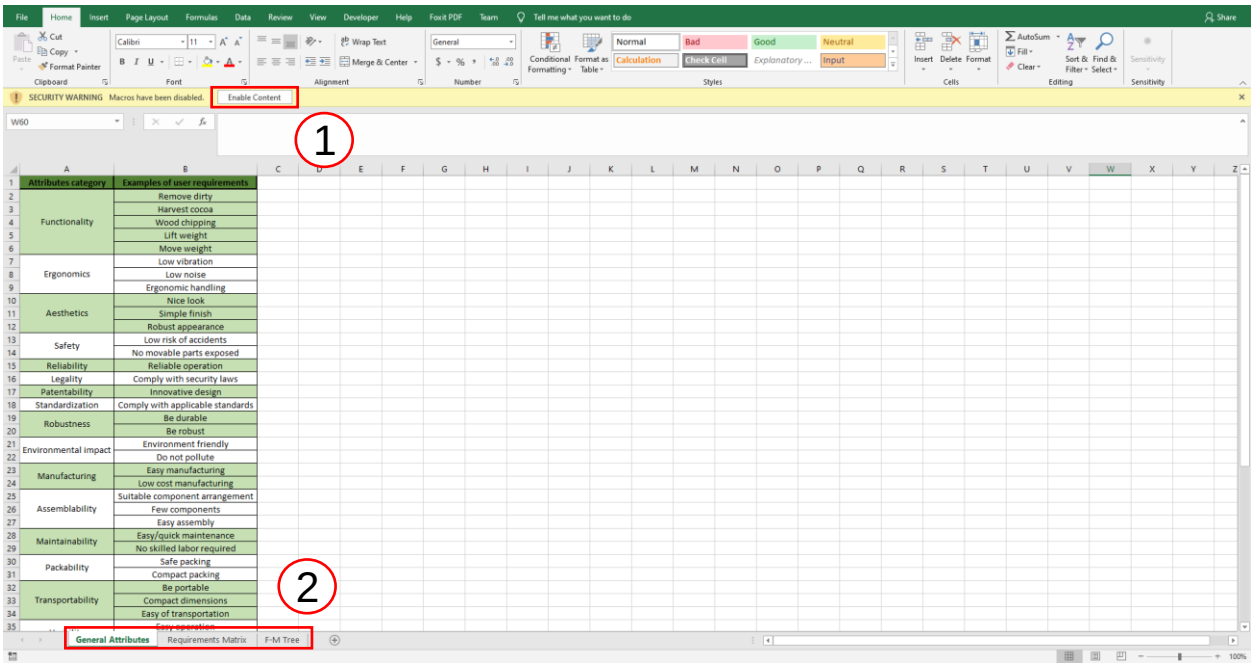

Figure 1: Excel's opening page

Initially, the workbook is composed of three sheets (Figure 1-2) which are: General attributes, requirements matrix, and F-M Tree. The General attributes sheet has a table with examples of commons user requirements, they are classified according to different categories, such as functionality, safety, and maintainability. The user requirements presented in this table are just suggestions and the definition of the user requirements should not be restricted to the examples of this table.

1.2 The requirements matrix sheet

The second sheet has a model table for the requirements matrix, the yellow fields have a validation list in which the possible options are presented (Figure 2-1). The green fields will be automatically filled according to the methodology equations. The light orange fields are set up for typing information, such as user and design requirements.

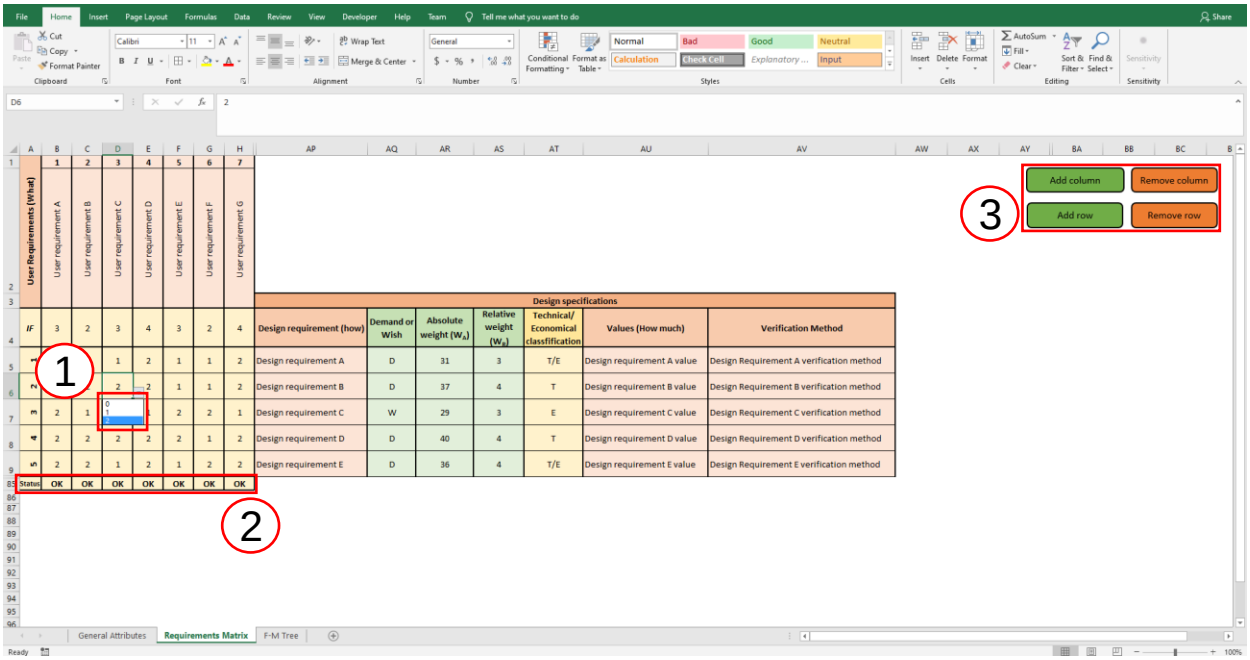

Figure 2: Requirements matrix sheet

Every user requirement must have, at least, one strong relationship (2) with a design requirement. The “Status” line (Figure 2-2) indicates if there is a missing strong relationship in a user requirement.

The push buttons (Figure 2-3) can be used to add or remove rows and columns, according to the necessity (The data present in a row/column will be erased if the row/column is removed). **IMPORTANT:** Do not remove or add columns using the conventional method (right button of the mouse), because it will lead to selection errors of the columns used in further steps of the design process.

1.3 The F-M tree sheet

The F-M Tree sheet (Figure 3) has a set of buttons that are used to create a function-means tree using the native excel shapes. The purple arrows define the sequence that the buttons are usually used, starting with the creation of the global function. The button called “Create new Operating Mean” will only be used when an operating mean has been achieved.

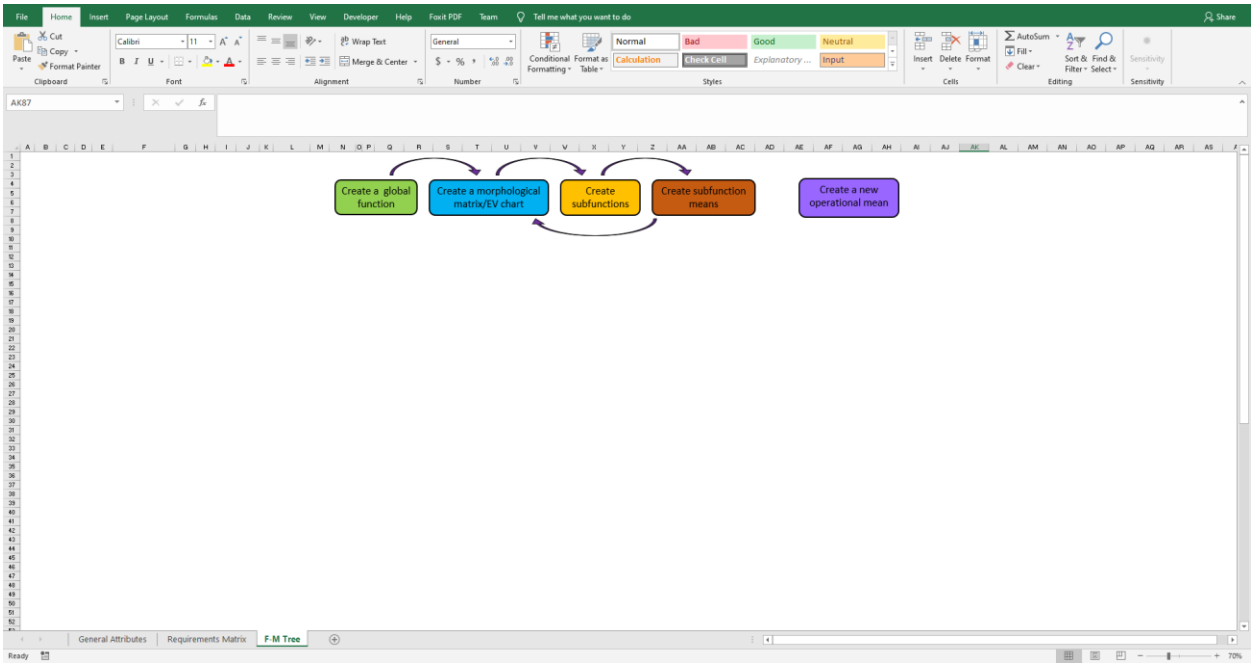

Figure 3: F-M tree sheet

1.4 Create a global function button

The Create global function button opens a window with two textboxes (Figure 4). In the first textbox, the global function should be written. The corresponding means can be written on the second text box, they have to be separated by a semicolon (;). To jump to a new line, press the keys “Shift” and “Enter” simultaneously. The last mean cannot end with a semicolon (A warning message will appear if an inconsistency is present in the means field).

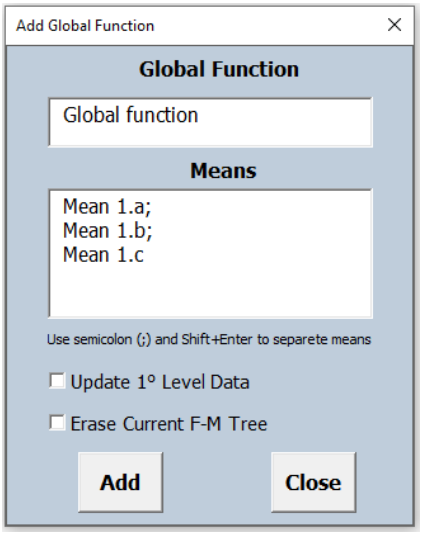

Figure 4: Add global function window

The checkbox “Update 1° Level Data” is used to rewrite the information in an existing mean box. If this option is selected, a message box will pop up asking if the current data of the first level should be deleted or not.

The checkbox “Erase Current F-M Tree” can be used to write a completely new F-M tree. It will erase all the shapes that are present in the F-M tree sheet. **OBS:** If this option was selected and a shape has not been deleted, you can click on the remaining shapes and press “delete” on your keyboard.

When the “Add” button is pressed, the information written in the fields will be used to create the first level of the F-M tree, as can be seen in Figure 5. The global function will be written in a trapezoid shape and the means will be written in a light green rectangle, which is called the means box. The dark green rectangle is called the selected mean box, it is a designated space to write the select mean of the function.

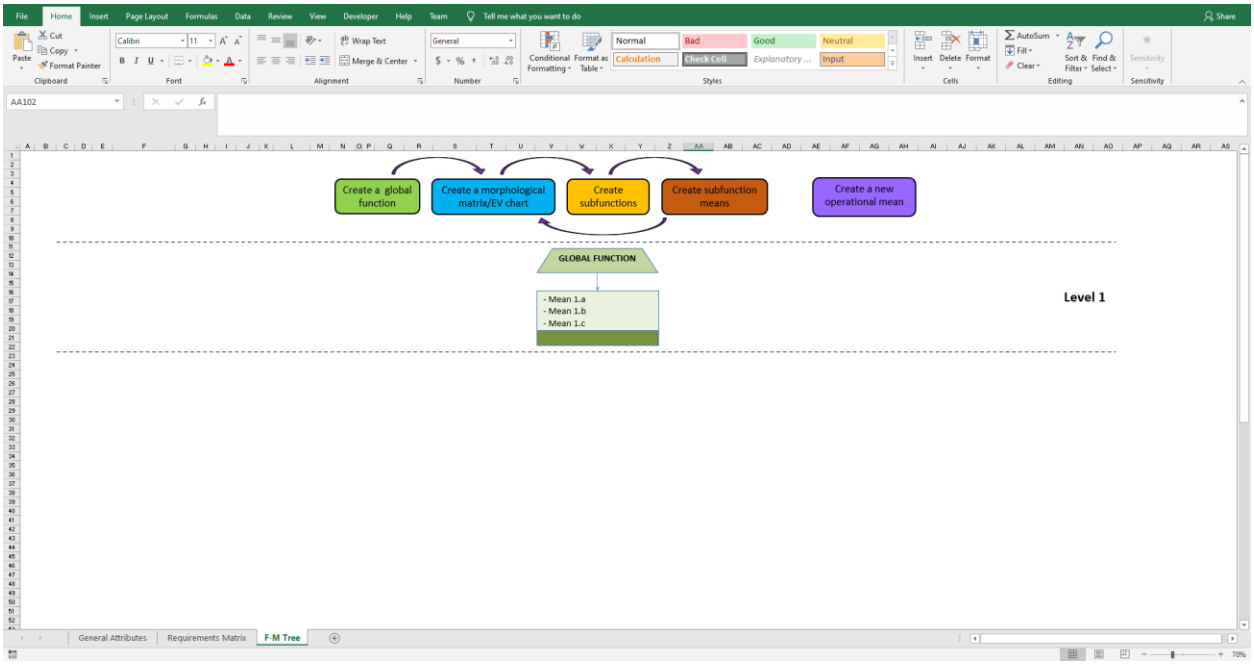

Figure 5: First level of the F-M tree

If it’s necessary to adjust the size of the shapes, just click on the shapes and use the perimeter dots (Figure 6) to adjust its size according to the necessity. To move the shapes, it’s possible to use either the mouse or the “Up”, “Down”, “Left” and “Right” keyboard keys.

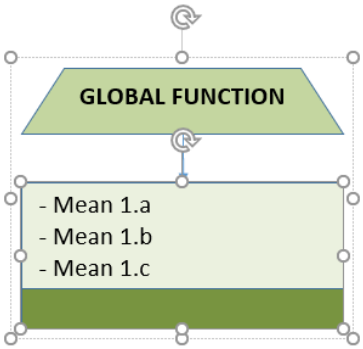

Figure 6: Perimeter dots to adjust the shape size

1.5 Create a morphological matrix/EV chart button

The next button is called “Create morphological matrix/EV chart”, it is used to gather the information of the functions and means of a level and create a morphological matrix or an evaluation chart. When a level is selected, it detects the number of subfunctions and operating means of this level and decide if it’s necessary to create a morphological matrix or an evaluation chart. A message is displayed to inform which action will be taken (Figure 7). When the “Generate” button is pressed, a new sheet will be created and a morphological matrix or an evaluation chart will be created. Usually, the evaluation chart will be created just for the first level, for the next levels, morphological matrices will be generated.

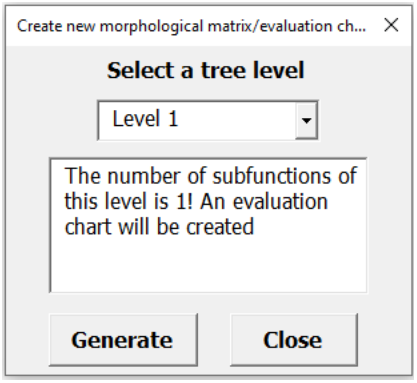

Figure 7: Create a new morphological matrix/Evaluation chart window

1.6 Level 1 Sheet

Figure 8 presents an example of a Level 1 sheet. It contains an evaluation chart with the means of the first level (Figure 8-1) and the design requirements from the evaluation matrix (Figure 8-2). The relative weight (W_r) and the design requirements will be automatically linked with the values of the evaluation matrix.

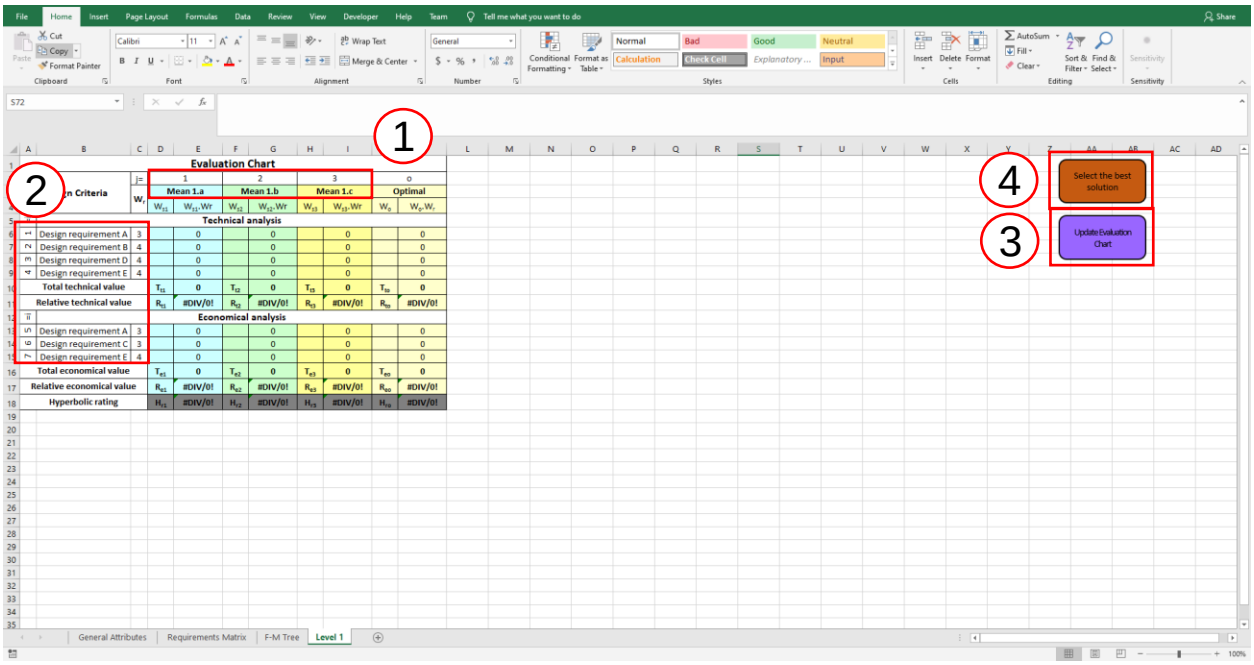

Figure 8: Example of a Level 1 sheet

The button “Update Evaluation Chart” (Figure 8-3) can be used to insert/remove design requirements and means from the evaluation chart. For instance, if a specific design requirement does not apply for this analysis, it’s possible to remove it from the evaluation chart by selecting the “Design Requirements” and the “Remove” option (Figure 9), then, on the dropdown list, it is possible to select which design requirement will be deleted. To insert a new design requirement, the option “Insert” has to be selected and then, all the design requirements from the Requirements Matrix will be available on the dropdown list. A similar procedure can be followed to insert/remove means from/to the Evaluation Chart.

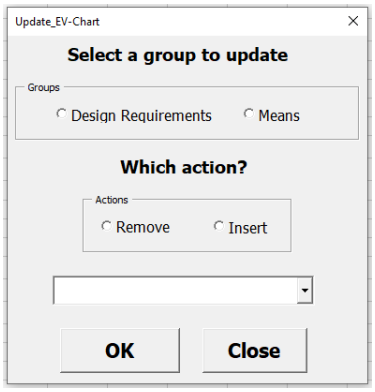

Figure 9: Update evaluation chart window

After all the values of the evaluation chart are correctly filled, the button “Select the best solution” (Figure 8-4) should be pressed, it will get the solution with a higher hyperbolic rating and write it on the F-M tree. After that, return to the F-M tree sheet.

1.7 Create subfunctions button

The next step of the F-M tree construction is the definition of subfunctions for the selected mean of the first level. Pressing the “Create subfunctions” button opens a window where the level and the mean which will be decomposed in subfunctions have to be selected (Figure 10). The next step is to write the subfunctions on the text box, which have to be separated by a semicolon (;). To add a new line, press the keys “Shift” and “Enter” simultaneously. When all the subfunctions are added, just press the “Add functions” button and the subfunctions will be written in the F-M tree (Figure 11).

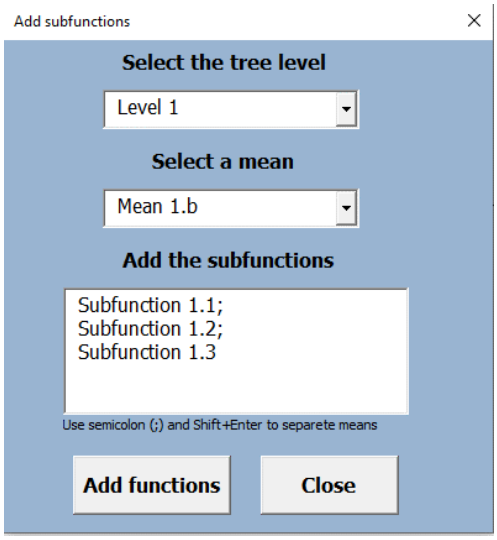

Figure 10: Add subfunctions window

When subfunctions are added to a mean, a new level will be created. In this case, the subfunctions of the first level (Mean 1.b) resulted in the second level of the F-M tree.

If it’s necessary to add subfunctions to a mean which already have subfunctions associated, it is possible to follow the same process. Click on Create subfunctions, select the level and mean, write the new function on the text box and finally click on the “Add functions” button, the new function will be added to the corresponding mean. However, when new functions are added to a mean which already has functions associated, the spacing of the new shapes will not be correctly adjusted. In this case, selected the shapes and manually adjust them according to the available space in the F-M tree (see section 1.11).

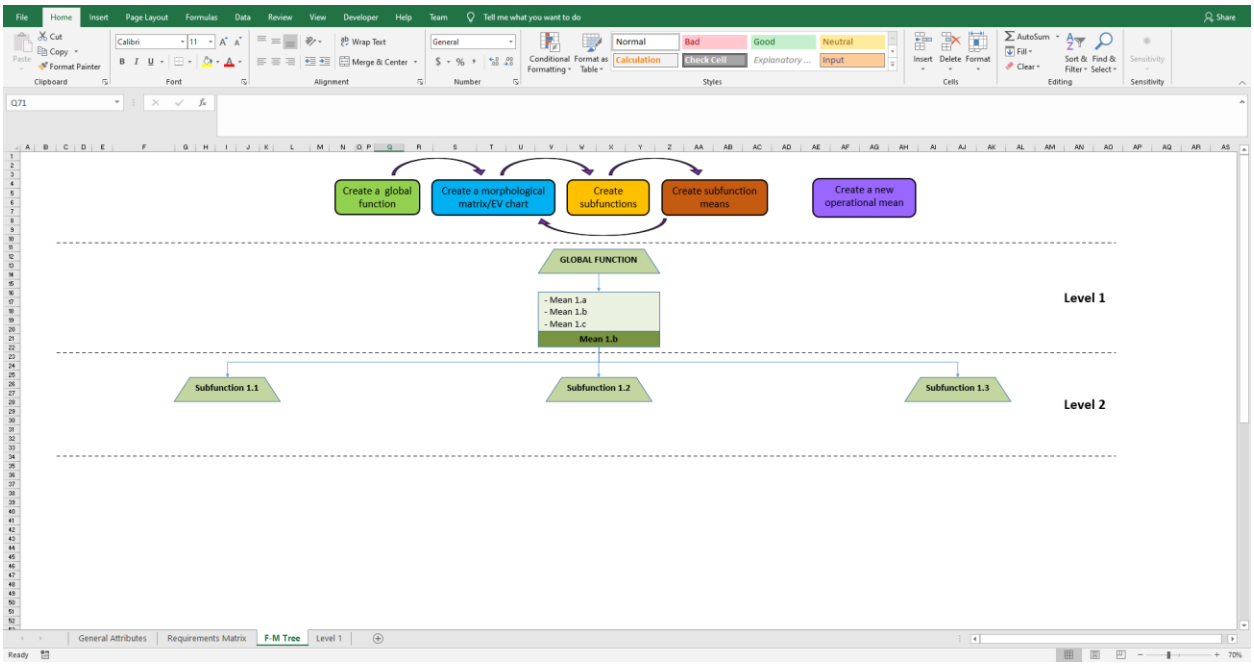

Figure 11: Second level of the F-M tree

1.8 Create subfunction means button

The next step is the definition of possible means for the new subfunctions. The button “Create subfunction means” opens up a window where the level and the subfunction in which the means will be added can be select (Figure 12). The means of the subfunctions can be written in the text box, they have to be separated by a semicolon (;) and new lines are added by pressing the “Shift” and “Enter” keys simultaneously. Finally, click on the “Add means” button to add the means in the F-M tree. Repeat the process for all subfunctions of the current level

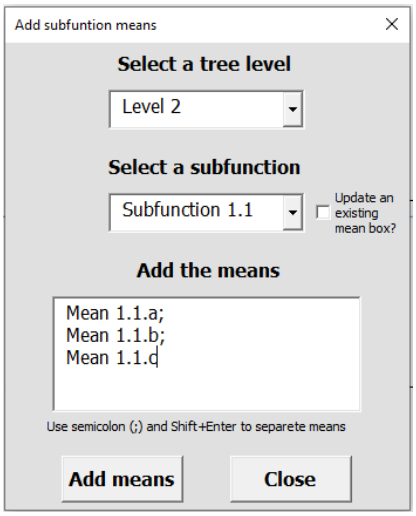

Figure 12: Add subfunction means window

The “Update an existing mean box” checkbox has to be selected whenever an update is necessary for an existing means box. For instance, if it’s necessary to add a new mean to a mean box which is already present in the F-M tree, select the corresponding level number and subfunction, write the new mean and mark the checkbox, finally, click on the “Add means” button. A message will pop up asking if you want to erase the current data of the mean box, click Yes or No and then the new mean will be automatically written in the corresponding mean box.

If it is necessary to make small changes in the texts of the shapes (Means or functions), just click on the shape and delete/add the information that you want. The texts on the shapes are editable.

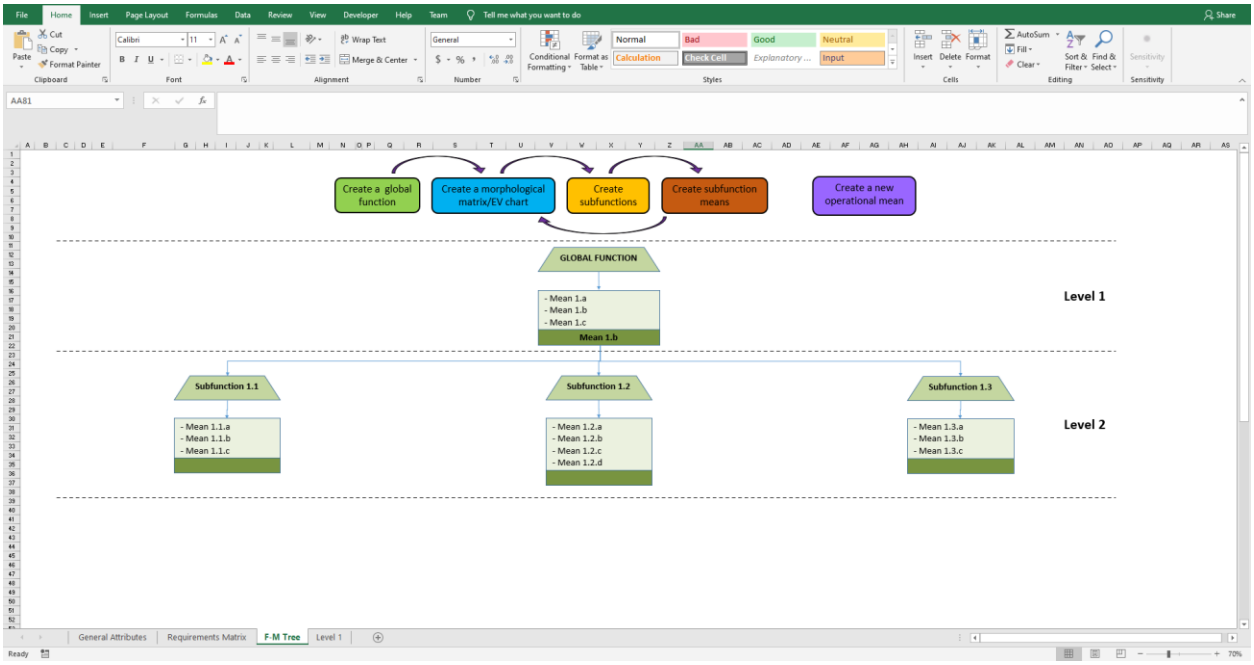

Figure 13: Second level of the F-M tree

Figure 13 presents an example of the second level with all the means of the subfunction defined. The next step is the definition of one specific mean for each subfunction, to do that, click on the “Create morphological matrix/EV chart” button and select the second level. It will identify the number of subfunctions of this level and warn that a morphological matrix will be created (Figure 14). Click on “Generate” to create a sheet for the second level

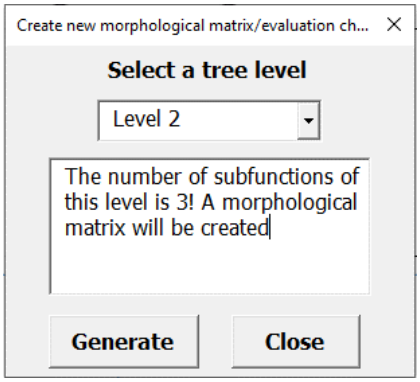

Figure 14: Create a new morphological matrix/Evaluation chart window

1.9 Morphological matrices

When a level contains two subfunctions or more, or there are one function and one operating mean (At the same level or in other levels), a morphological matrix will be created instead of an evaluation chart. The morphological matrix will be created in a new sheet with the name of the level of the subfunctions. In Figure 15 it is presented the morphological matrix for level 2 of this example.

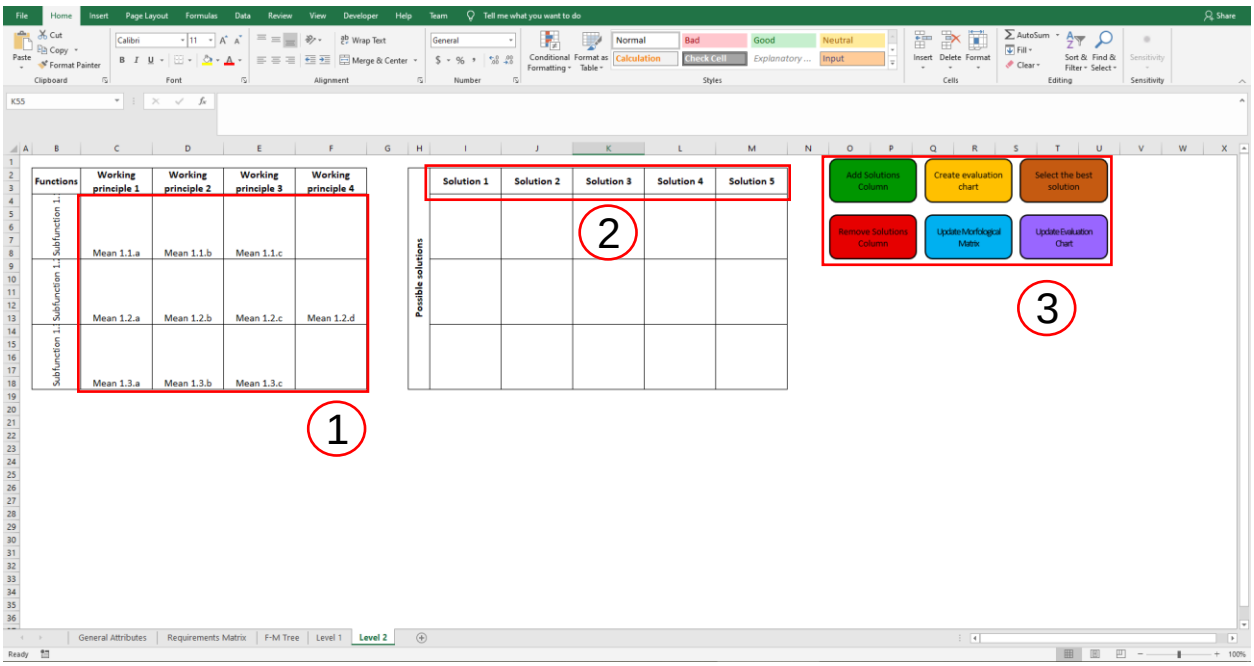

Figure 15: Example of a morphological matrix

The morphological matrix will be formatted according to the subfunctions and means of the selected level. As can be seen in Figure 15-1, there is a blank space where a picture of the means can be pasted. The pictures can be copied from free images websites and pasted on the worksheet (select a cell outside the morphological matrix to paste the image, then resize the image and drag it to the mean box. If

necessary, use the excel picture tools to crop the image).

After pasting all the means pictures, it is time to create possible solutions, which are combinations of working principles (means). Initially, the sheet will have five columns formatted to paste working principles (Figure 15-2), which results in 5 possible solutions. Just copy a working principle cell and paste it into a possible solution cell (the picture will be copied with the mean name). Use the “Add/Remove solutions column” button to create or delete the solutions columns if needed (Figure 15-3).

If it is necessary to add or remove functions from the morphological matrix, the button “Update morphological matrix” can be used (Figure 15-3) which will open the window of Figure 16. If a new function was created in the F-M tree and it needs to be added to the morphological matrix, select the “Add function” option, and all the functions present in the F-M tree of the current level will be presented, select the function to be added and click “OK”. If a function has to be deleted from the morphological matrix, select the “Remove function” and all the functions present in the morphological matrix will be presented, select the function to be deleted and click “OK”. If it is necessary to update the entire morphological matrix, select the option “Update entire table” and click “OK”, in this case, all the functions and means of the morphological matrix will be updated **OBS:** The possible solutions table WILL NOT be updated.

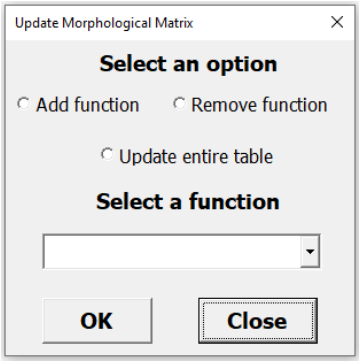

Figure 16: Update Morphological matrix window

When all the possible solutions are completed click on the “Create evaluation chart” button (Figure 15-3). It will create an evaluation chart with the design requirements from the requirements matrix and the possible solutions that resulted from the morphological matrix.

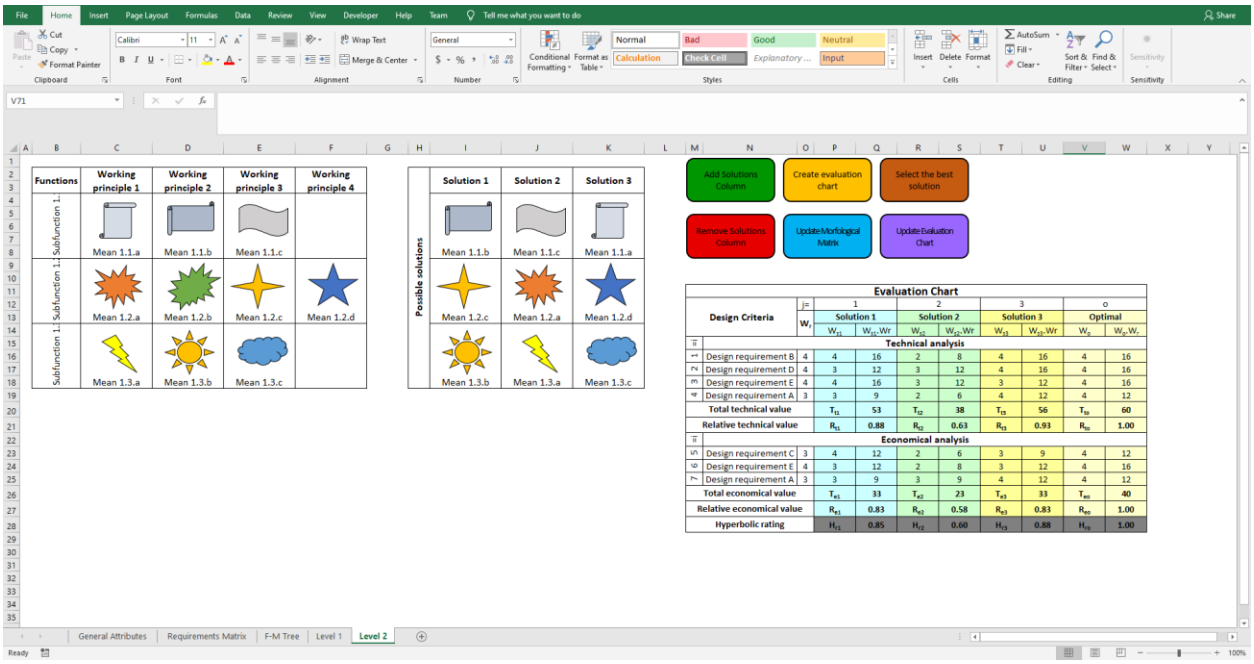

Figure 17: Example of a complete morphological matrix and evaluation chart

If it is necessary to insert/remove design requirements or possible solutions from the evaluation chart, you can use the “Update Evaluation Chart” button, similar to the explanation given in Section 1.6.

IMPORTANT: Two warnings have to be considered before creating the evaluation chart:

1°: Do not leave empty solution columns, the evaluation chart will always have the same amount of solutions that are present in the possible solutions table.

2°: Do not delete/insert columns before the evaluation chart (columns A to L in this example) these spaces are used as references to create the evaluation chart and to select the best solution.

When all the values of the evaluation chart are correctly filled, press the button “Select the best solution” to write the means of the solution with the highest hyperbolic rating at the F-M tree. After that, return to the F-M tree sheet.

1.10 Create a new operating mean button

The process described above should continue until all the selected means are classified as operating mean. An operating mean is an operational unit which the design team does not want to develop and it is commercially available. When an operating mean is achieved, it has to be classified in the categories of a mechatronic system, which are: Energy/material system, measuring system, actuation system, information system, output interface, and input interface. In the F-M tree, use the “Create new operating mean” button to open the window of Figure 18, where all the means which are not decomposed in subfunctions will be listed. Select the desired mean, choose its category and press “Add Operating Mean”. A category box will

be created below the selected mean box to indicate that it is an operating mean (Figure 19-1 and 2).

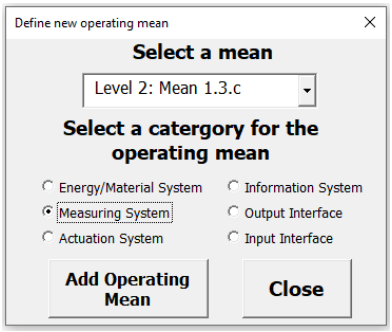

Figure 18: Define new operating mean window

When a mean is classified as an operating mean it will not be displayed in the “Add subfunctions” window. Also, the subfunction which originated the operating mean will not appear in the “Add subfunction means” window. However, all the operating means will be present in the following morphological matrices.

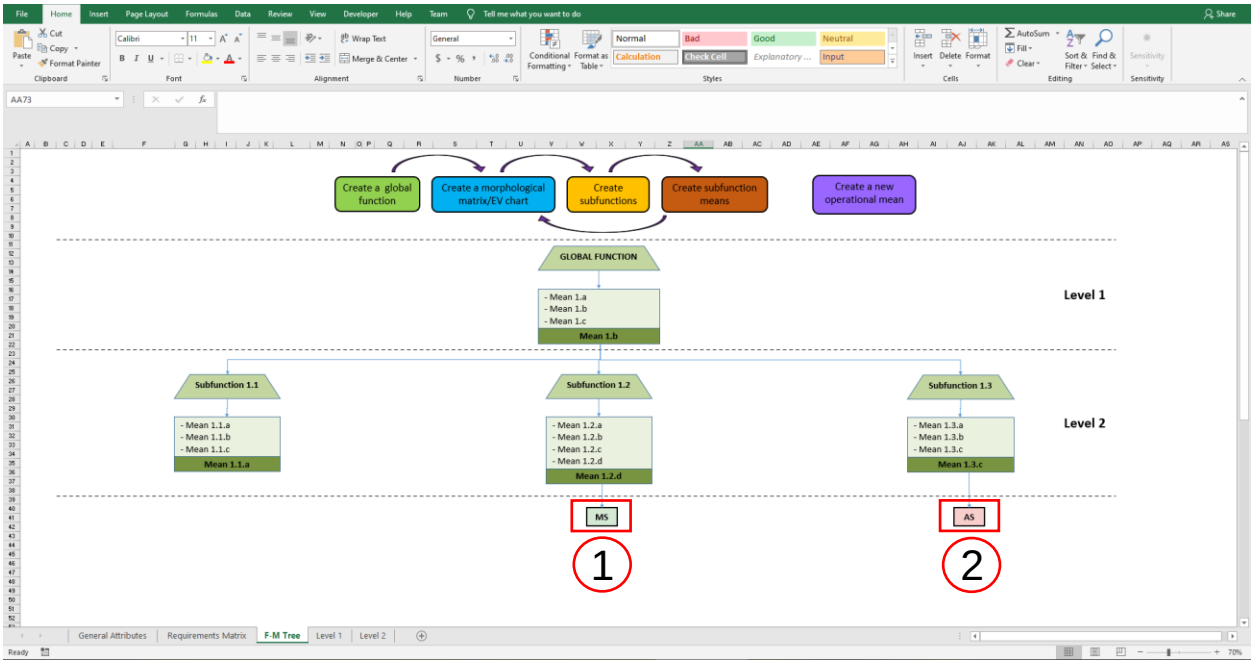

Figure 19: F-M tree with operating means

In this example, the only mean that will be decomposed is the “Mean 1.1.a” since the other means are already defined as operating means. The decomposition will use the “Create subfunctions” and “Create subfunction means” buttons. The result is presented in Figure 20.

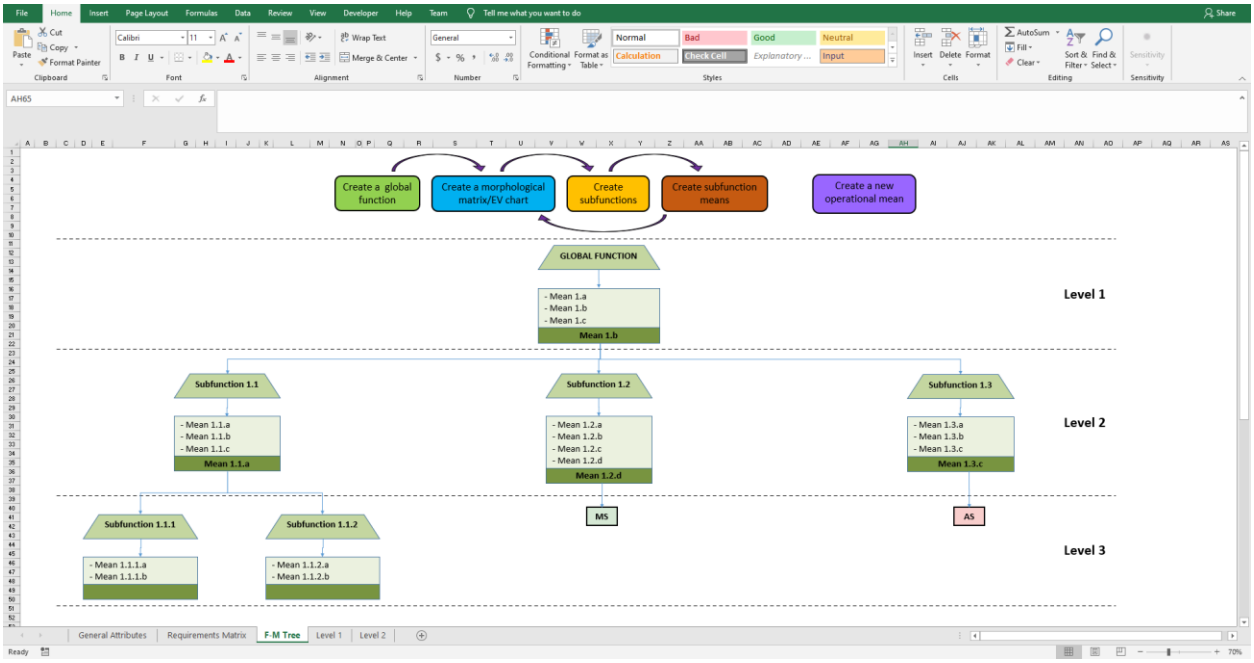

Figure 20: Third level of the F-M tree

The corresponding morphological matrix is created by using the “Create morphological matrix/EV chart” button, which results in the “Level 3” sheet and is presented in Figure 21.

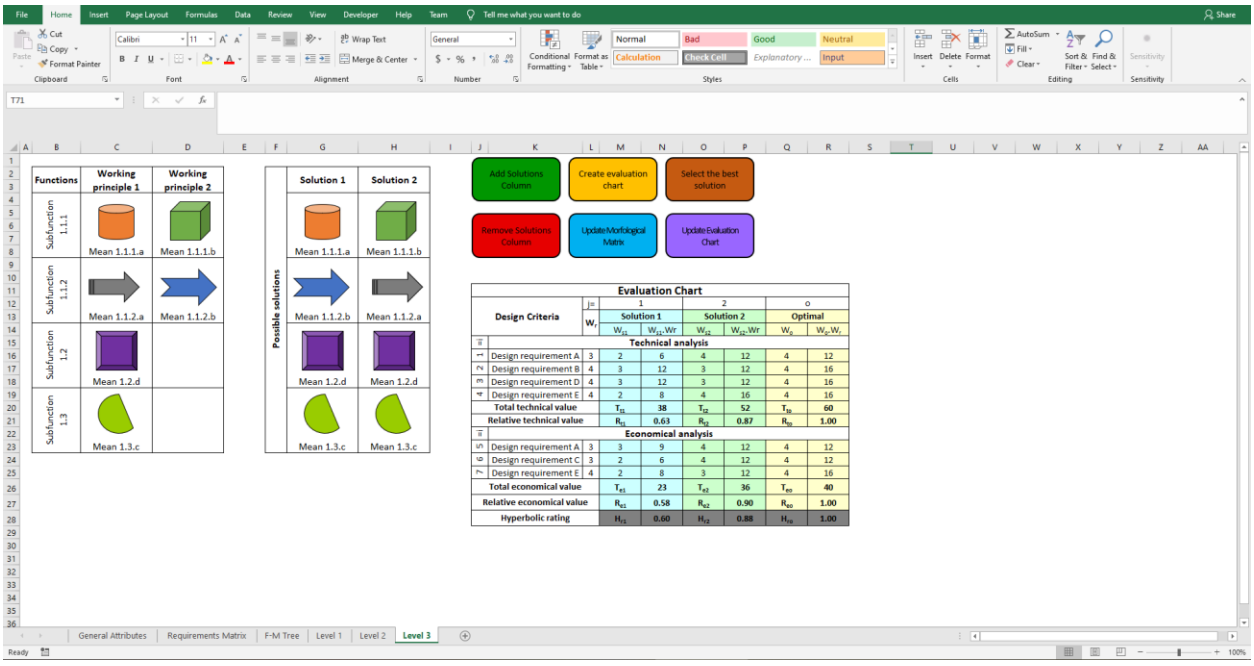

Figure 21: Level 3 morphological matrix and evaluation chart

After pasting the pictures of the morphological matrix, two possible solutions were generated. The solutions columns 3, 4, and 5 were removed by pressing the “Remove Solution Column” button. The evaluation chart was created by pressing the “Create evaluation chart” button. Through the evaluation chart,

solution 2 has shown to be the best, thus, the means of solution two were written in the F-M tree by pressing the “Select the best solution” button.

Back on the F-M tree, the two selected means of the third level are classified as operating means. Therefore, the construction of the F-M tree is finished (Figure 22).

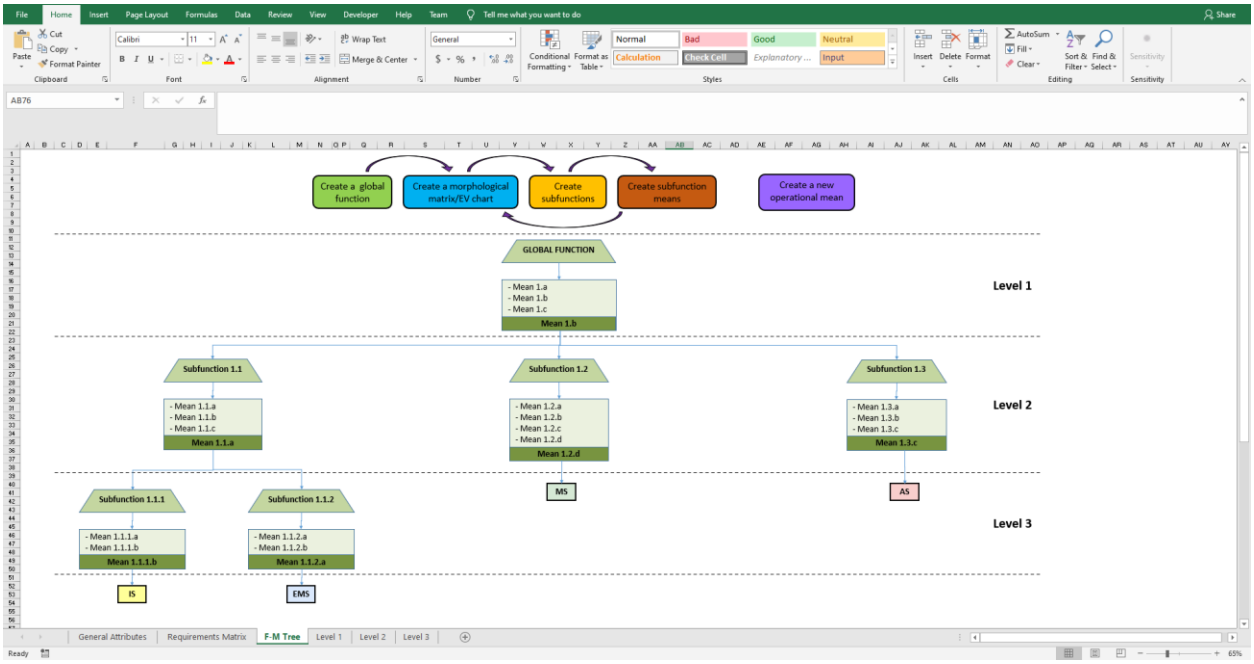

Figure 22: F-M tree completed

In this example, the F-M tree finished at the third level. However, this designing tool is capable to build F-M trees up to 20 levels with 30 subfunctions in each level, so it can handle the design of almost any mechatronic system.

1.11 Shapes positioning

The excel tool is programmed to automatically set the position of the shapes. However, depending on the size and the format of the F-M tree, the auto-positioning will not produce a suitable result. Also, when additional subfunctions or means are added to an existing subfunction and means, the positioning will not be adequate, as can be seen in Figure 23-1, where and additional function was added to the mean 1.b

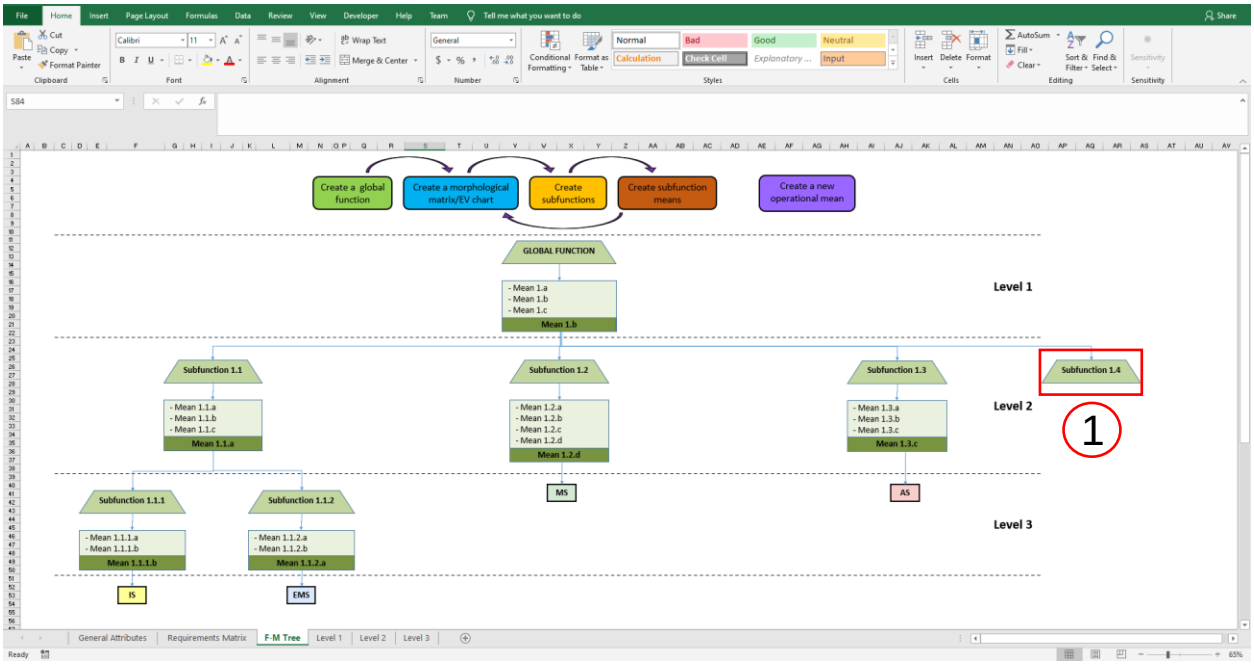

Figure 23: Adding an extra subfunction.

To easily position the new function, it is possible to use the excel align tools. In this case, the "distribute horizontally" and the "align top" are two good options to correctly position all the shapes of the second level. First, drag the "Subfunction 1.4" to the left (do not worry about the vertical alignment), then select all the second level shapes ("Ctrl" and right-click on the shapes) and click on "Distribute Horizontally" (Figure 24-1).

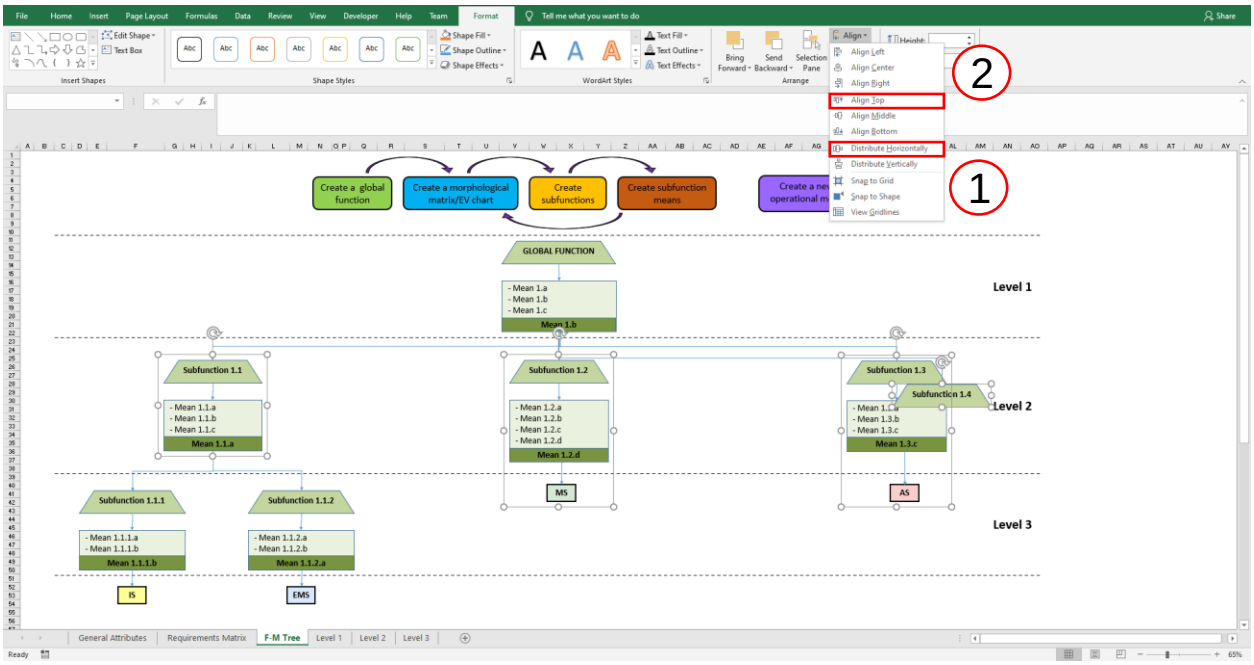

Figure 24: Distributing and aligning level 2 shapes

After that, click on “Align Top” (Figure 24-2) in the same menu (with the shapes still selected) and all the shapes will be aligned and in a nice distribution, as can be seen in Figure 25.

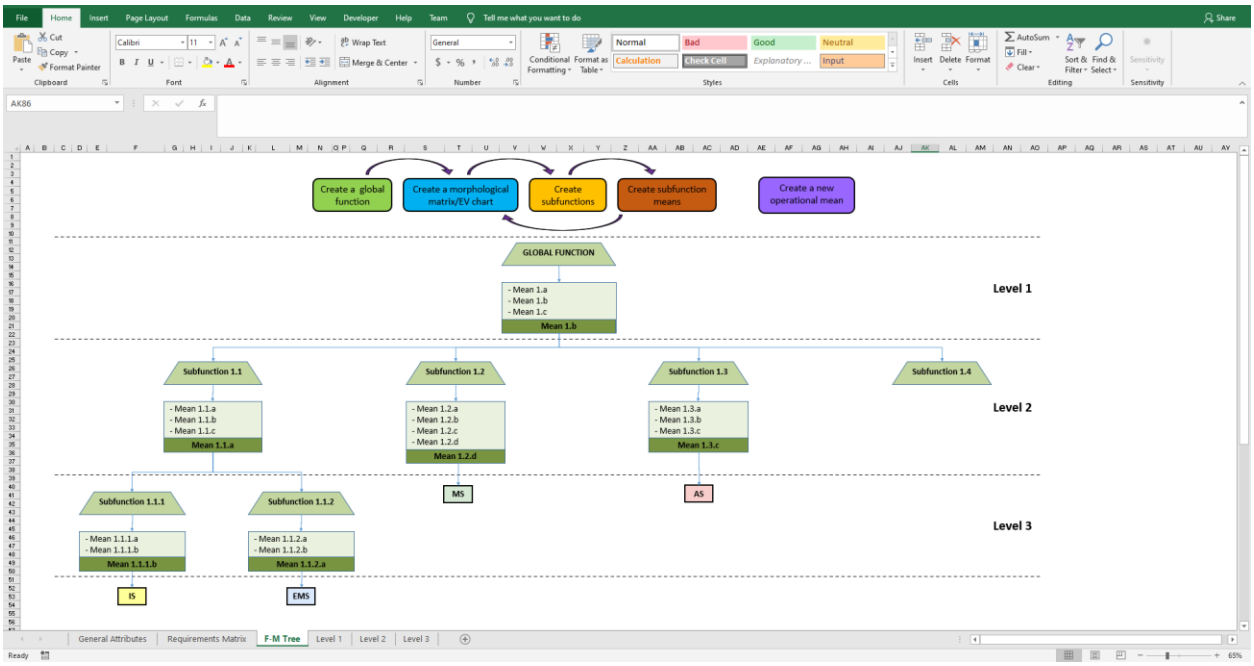

Figure 25: New alignment and distribution of the second level shapes

1.12 Level lines length

If the F-M tree is too wide to fit in the level lines that are automatically generated, they can be easily resized with the excel drawing tools. Select all the level lines (“Ctrl” + right-click) and set a new width for the lines (Figure 26-1). The level names can be moved with the keyboard left and right keys or by dragging them with the mouse.

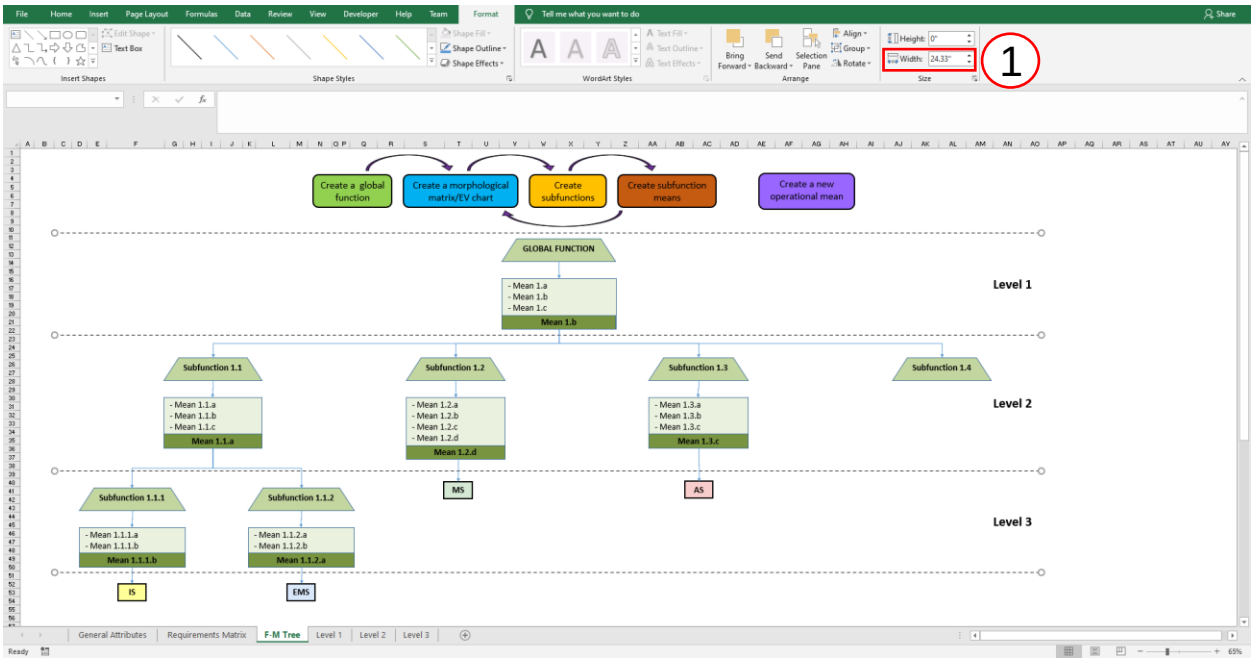

Figure 26: Adjusting the length of the lines

If it's necessary to restart the construction of a new F-M tree, delete all the levels sheets and use the "Create a global function" button to start a new F-M tree, it will erase all the shapes of the actual F-M tree. If any shape is not deleted, just click on it and press the delete keyboard key.

Since all the shapes and matrices are created using the native excel tools, feel free to edit as you need (change colors, sizes, move, etc). However, there are a few columns and rows that should not be deleted, as was explained in sections 1.2 and 1.9. If you have any question or suggestion about this excel designing tool, please send a message to vinicius.vigolo@laship.ufsc.br.