ASSESSING POTENTIAL FOR URBAN RIVERS' REHABILITATION THROUGH AN ADITIVE AGGREGATION MULTICRITERIA MODEL[1]

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1. Introduction

Following the Multiattribute Value Theory for multi-criteria decision support, based on Value Measurement Theory (Keeney and Raiffa, 1976; Roberts, 1979; Von Winterfeldt and Edwards, 1986) there are two fundamental components that should be considered: the first one is called *intra criteria* information and can use *Partial Value Functions*; the second component is called *inter-criteria* information and can use *weights* and *aggregation models* to get an overall evaluation of alternatives.

In the case of the rehabilitation potential of urban rivers the aim of the evaluation process can be to compare alternatives, which sometimes are also called "options" or "actions", in order to choose the best ones. This choice process can be done using the very well none and also intuitive weighted sum method also called as "additive aggregation model".

Through this model different criteria are aggregated in a single synthesized criteria, which resumes all evaluative dimensions that are being modelled, using an additive function. In order to express the appropriate values of DM (Decision Makers) this additive function can use Partial Value Functions – expressing performances into values – and weights – the compensation trade-offs between criteria.

2. Eliciting Scores

A set of criteria are normally chosen when a multi-criteria methodology is being applied. In the modelling process, very often, these criteria are in fact indicators

[1] Contribution from Urbem-Partner nr.7 to WP5.

because they only indicate (or represent) the impact of alternatives on the correspondent viewpoints, at least in terms of order. Scoring is the process of assessing the value derived by DM from the performance of alternatives following each criterion, which can be made using value functions.

> "*Value Functions* are a mathematical representation of human judgements. (…) translates the performance of the alternatives into a value score, which represents the degree to which a decision objective (or multiple decision objectives) is matched" (Beinat,1995:8).

Figure 1 and Figure 2 are examples of the assessment where specific interviewing procedures, mediated by an analyst (or facilitator), have to be made with DM. In the case of Figure 2 an increment of +1 landmark (0 → 0,5L/km2) in a river corridor (where no landmarks have been detected) is four times more relevant (+0,4 in the value scale) than an equal increment of +1 landmark (0 → 0,5L/km2) when the same stream has already 3 landmarks (1,5 → 2L/km2) present in the landscape. By other words, a small increment can be more valuated by the DM in a context of great scarcity than in a landscape plenty of landmarks (like in River Thames at London, or River Seine at Paris, for instance). Three-dimensional value functions are also possible.

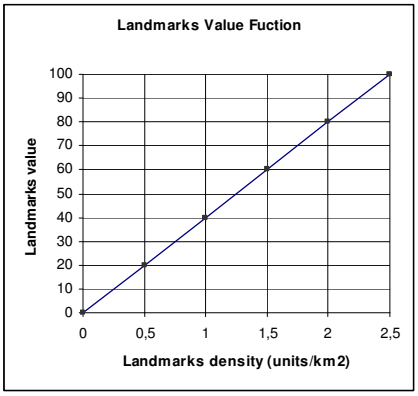

Figure 1 - Example of a linear value function applied to the evaluation of rivers in terms of landmarks indicator

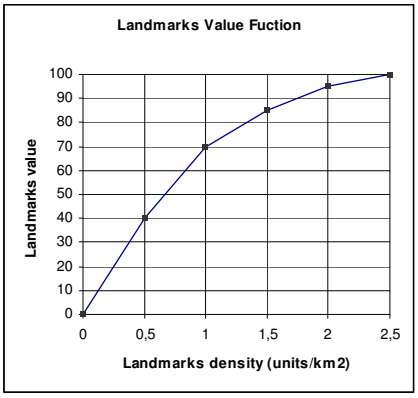

Figure 2 - The same example using a non-linear value function.

MCDA literature refers several methods to assess value functions. The most common are:

- Direct rating (Von Winterfeldt & Edwards, 1986);
- Bissection Techniques (Goodwin & Wright, 1997);
- Semantic Judgement (like Macbeth[2] method – Bana e Costa and Vansnick, 1994).

Direct Rating requires the specification of the value attached to a score. I the upper and lower limits are clear in terms of their effects, the evaluator/facilitator/analyst states the value of the point x in such a way that 100-v(x) and v(x)-0 represent the difference in attractiveness between the lower limit, x and upper limit of the attribute.

In the *Bissection Technique* the DM identifies the more preferred stimulus and the least preferred. Afterwards, the central stimulus should be found in such a way that is equally distant of both limits.
"What is the value of x for which, in terms of impact, the difference of atractivity between 0 and x is equal to the difference of atractivity between x and 5 ? "
This is equivalent to the expression v(0)-v(x) = v(x)-v(5).

Semantic Judgement are used to help DM to express the difference of attractiveness between each pair of points (alternatives) with no need of quantative estimates. The value function, which represents judgments, is composed through linear optimisation, selecting the curves most consistent with the revealed preferences[3].

[2] Macbeth – Measuring Attractiveness by a Categorical Based Evaluation Technique (http://www.m-macbeth.com/Msite.html)
[3] Macbeth can also be used as a weighting procedure.

Having in mind that the multicriteria problem that we have in hands should deal with an open set of alternatives (rehabilitation projects) which may be incomplete at the beginning of the evaluation process, it was considered more appropriate to work (as much as possible) with global scales.

A global scale, instead of local scales, is defined by reference to a wider set of alternatives. For this reason, the upper and lower limits were defined by the maximum and minimum plausible performance on each specific criterion, which could realistically occur. The main advantage is that it can be defined before knowing all specific set of watercourses under evaluation. Other reference points, like "good" and "neutral" can also be used instead of extreme points (Bana e Costa and Vansnick, 1999).

3. Eliciting Weights

The weights usually assigned to criteria, which are commonly referred as the "relative importance" of criteria, are in fact scaling factors that relate scores on one criterion with scores on all other criteria.

If DM values equally 10 value points on C_i against 20 value points on C_j, this means that $w_i=2w_j$ (Figure 3).

Trade-off procedure (Keeney & Raiffa, 1976), *Swing-Weighting* procedure (Von Winterfeldt & Edwards, 1986), *Ratio Procedure* (Edwards & Newman, 1982) and *Macbeth* (Bana e Costa & Vansnick, 1997) are the main methods of eliciting weights.

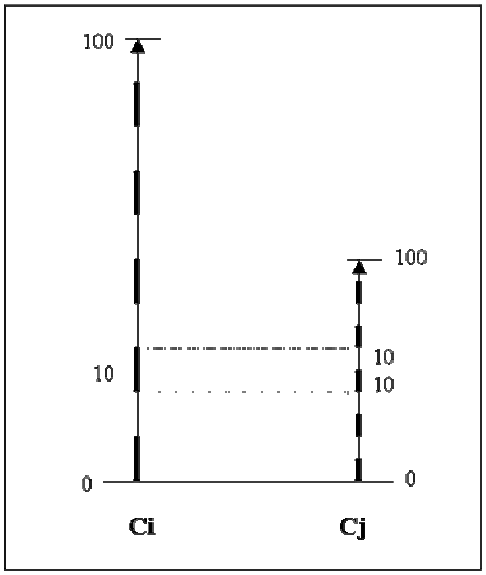

Figure 3 - Weights as scaling factors

Let us consider that the several evaluative dimensions of a given urban river under a rehabilitation process can be structured as a multilevel value tree. In this case it is possible to assign weights within the same family (elementary viewpoint) progressing, by cumulative weights, to the top of the tree.

The following protocol of questioning can guide the elicitation of weights by the application of *swing weights* procedure to the elementary viewpoints:

> "Analyst – Consider the river you are evaluating. Imagine this same (or a similar) river performing zero on all criteria (the worst plausible state). Imagine that it is possible to increase just one criterion from 0 to its maximum level. Which criterion would you chose?.
> DM – I would prefer to increase C_{23}.
> Analyst – OK. You have chosen the criterion C_{23}, which means that C_{23} should have the highest weight. Now imagine that something can be done in your hypothetical river in such a way that the performance of the criteria you have chosen becomes the maximum (100). But all other criteria performances remain zero. What would be, this time, the second criterion to be raised to the maximum value?
> DM (…)
> (The analyst goes on until an ordered set of criteria is obtained. In this way all criteria, and their correspondent weights, became ordered from the highest to the lowest)
> Analyst – We have now a rank order for the criteria weights. Now… consider that, on the first criteria (C_{23}), the swing from minimum to maximum is valuated in 100. How much can you valuate an identical swing in the second, third and all other criteria as a % of that increase? "

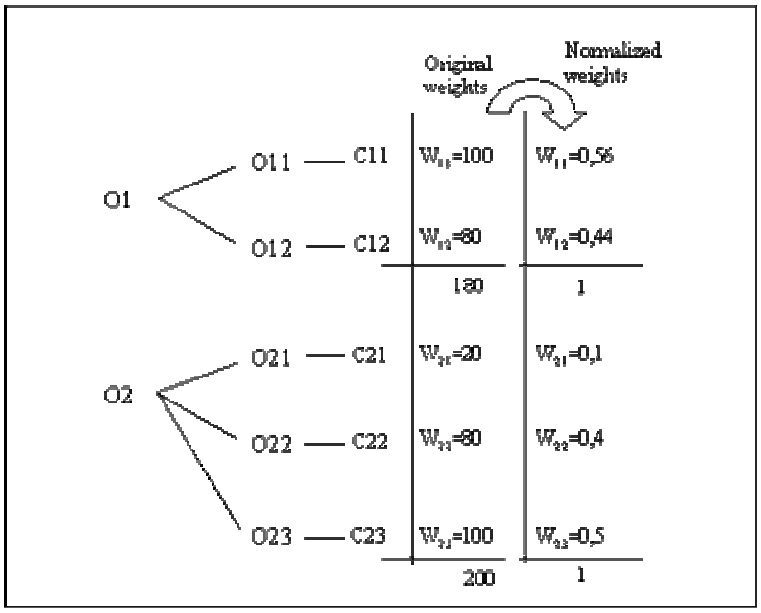

Figure 4 – Normalizing weights at the same level

The weights obtained by this questioning protocol can now be normalised in order to have $\sum w_i=1$ (or $\sum w_i=100$). This process should be done in each level and in each criteria family of the value tree, which allows the aggregation of values to higher levels using a bottom-up approach (Figure 4).

4. Absolute and relative values

Arrived at this stage it is pertinent to ask if it is possible to elicit weights without considering the local characteristics of the case study that we have in hands, which is the same to ask if it is possible to fix global weights independently of a specific river and their alternatives.

It should be remarked that, in this case, the protocol of questioning could start like this:

> "Analyst – Consider a generic (European) river that is being evaluating. Imagine this generic river performing zero on all criteria (the worst plausible state). Imagine that it is possible to increase just one criterion from 0 to its maximum level. Which criterion would you chose?.
> DM – (…)
> (etc.)

Regarding some evaluative dimensions it seems very difficult to establish a stable preference system that is independent from local realities and values. The value

and relative importance of some dimensions (like "Natural Components", "Ecological Performance" to local communities, as well as the "Cultural Heritage" or "Pollution", for instance) are intrinsically dependent of the social, cultural and political local context. Because of this, in some countries, where the problem of rivers pollution is still uncontrolled, "Pollution" will probably become more weighted. In other countries, with a strong culture in preserving the natural appearance of riverbeds that can even be a common value protected by the practitioners and institutions, "Natural Components" can be less weighted by DM just because it is a common practice.

Instead, it seems possible to make an *ex ante* relative evaluation of the rehabilitation *alternatives* (*options* or *potential actions*), for a specific river, in order to rank or select those alternatives. This seems more plausible because the preference system will be likely more stable and more coherent although still and always dependent of the individual preference system of the DM involved in that process.

5. Aggregation model

In Value Measurement Theory the form of aggregation used is central and is interrelated with weights. The use of an aggregation function that relates all criteria in one single criterion allows DM to compare the global performance of alternatives. The mostly used form of aggregation is the *additive aggregation function*, $V(a)=\sum w_i v_i(a)$, which will also be used in our context of evaluation. It is a form that can be easily explained and understood by DM with different backgrounds.

Like in the case of potential rehabilitation evaluation, if criteria are associated with indicators (or descriptors) acting as measurable attributes z_i , defined on cardinal scales that measure unambiguously the impact of any alternative in each criteria, than the additive aggregation function can be expressed in the form
$V(z) = \sum w_i v_i(z_i)$.

In the case of a multilevel value tree, some sort of hierarchical aggregation formulae is needed. In the case of a value tree with two hierarchical levels of criteria, M and N, the additive aggregation requires some assumptions that need some care in defining criteria, in interpreting value functions and weights:

- Preferential independence of criteria;
- Accepting trade-off between criteria;
- The use of interval scale of preferences in order to assure that equal increments in $v_i(z_i)$ represent in fact equal trade-offs.

These assumptions should be well accepted and adapted in each case. But it is possible, considering this particular field of application – rehabilitation of urban rivers - that "indifference" or "incomparability" situations arise, when DM did not have decisive evidence to express their preferences. In those situations other methods can be considered or even go back to the structuring stage and reformulate some part of the value tree.

The application of an aditive aggregation multicriteria model can be well illustrated in the case of Aesthetic Assessment of urban watercourses using the case study of Jardas Stream reported in Deliverable 4.3 of Urbem Project.

5.1. Aesthetical value profile - example

The application of this multicriteria approach to evaluate aesthetical values of Jardas stream[4], based on a framework of viewpoints and using an additive aggregation model, can be represented as a "value tree" with the help of commercial software (like VISA software[5], see Figure 5). "Public Perception" can also be represented on the same away (Figure 6). The "World" of People and the viewpoint of "Public Perception" was considered important to explain aesthetics however this tree was not weighted, i.e., all attributes represented, that contribute to "Public Perception", were all considered having the same relevancy. This means also that the DM may not know to express the trade-off between them or that some sort of compensation rule is not applicable to them. In fact, regarding the "world of people", at least in what respects the aesthetics relationship between river and city, the people opinion have been considered relevant to analyse the sensorial aspects of aesthetics and, therefore, to analyse and validate their relationship with other evaluative dimensions mentioned by experts.

[4] See also Urbem Deliverable 4.2.
[5] VISA- "*Visual Interactive Sensitive Analysis*", designed by Valerie Belton, Management of Science, University of Strathclyde, (http://www.simul8.com/products/visa.htm).

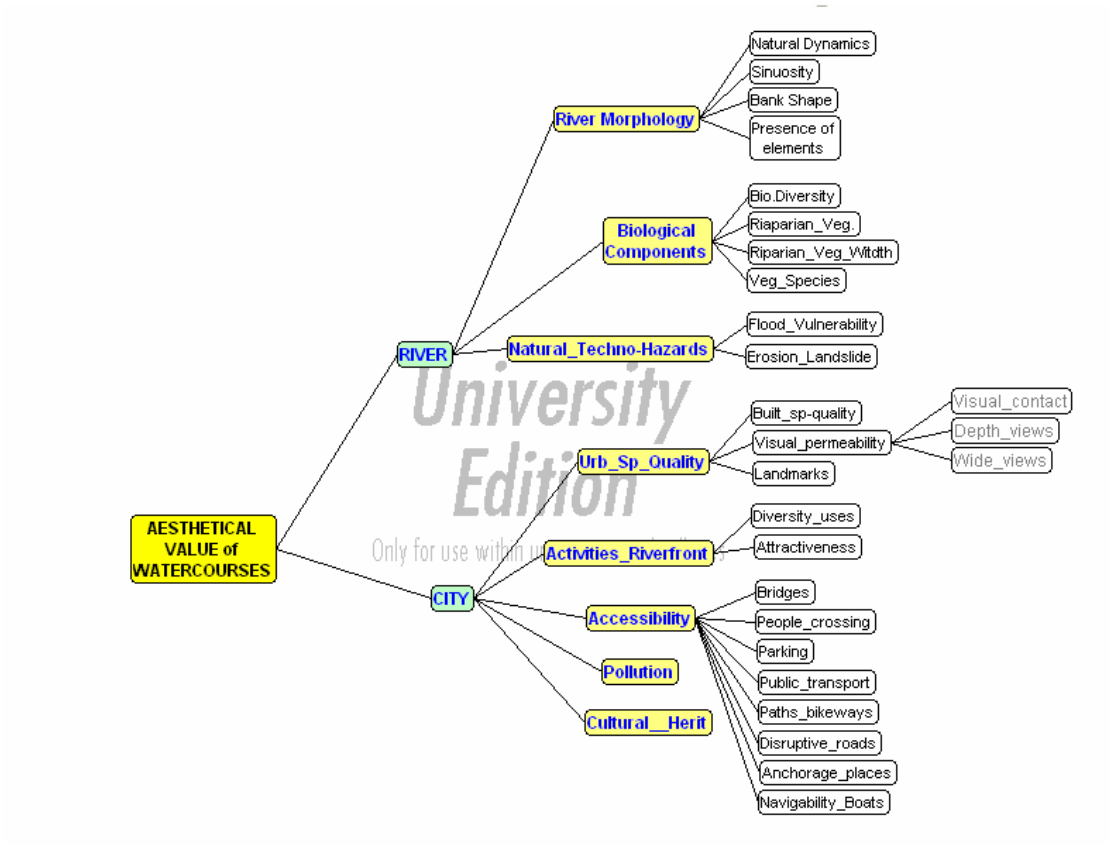

Figure 5 – Value-tree for Jardas Stream

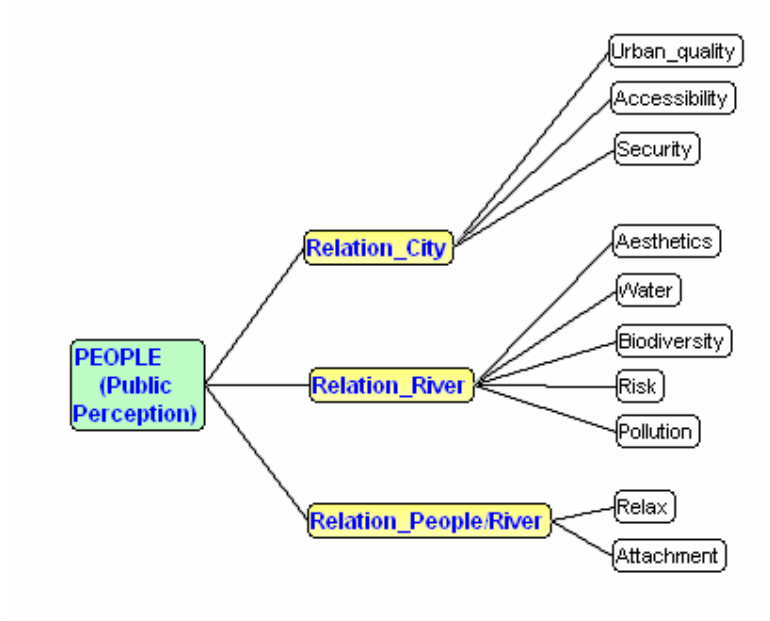

Figure 6 – Value-tree regarding the "World" of People (Public Perception)

As referred in §2, linear or non-linear value functions can also be used for each criteria. In this example we will use only linear value functions. This corresponds to a linear transformation from the indicators´ scales to criteria´ scales (0-100).

The use of the Questioning Protocol (referred in § 4.) will help DM or Decision Team to explicit different weights to each branch in each level of the tree.

Urban Space Quality:

(Analyst) – Consider the river you are evaluating. Imagine that this same river performs zero on all sub-criteria (the worst plausible state) – Built-Space-Quality, Visual-permeability, Landmarks. Imagine that it is possible to increase just one criterion from 0 to its maximum level. Which criterion would you chose?.

(DM) – Well… the built space is, in fact, the space where the people live their lives. I would prefer to increase first the Built-space-quality.

(Analyst) – OK. You have chosen the first criterion, which means that "Built-space-quality" should have the highest weight. Now imagine that something can be done in your river (like a project of urban rehabilitation) in such a way that the performance of "Built-space-quality" becomes maximum (100). But all other criteria performances remain zero. What would be, this time, the second criterion to be raised to the maximum value?

(DM) – Thinking in terms of "Urban-Space-Quality" … if "Built-space-quality" is fixed to '100' then I would prefer to increase "Landmarks" performance and, after raising this criterion, then the "Visual-permeability". I can admit that visual permeability can be very important in terms of opening perspectives and visual axes, even to see the landmarks but, in this case, I consider more important to have reference points in the urban landscape.

(Analyst) – Very well … we have now the ranking for these 3 criteria weights.

1st- Built-space-quality

2nd - Landmarks

3rd - Visual-permeability

Now… consider that, on the first criteria, the swing from minimum to maximum is valuated in 100. How much can you valuate an identical swing in the second and third as a % of that increase?

(DM) – If the swing 0→100 (or min→max) in "Built-space-quality" means a value of 100 points then, I will say that the swing 0→100 in "Landmarks" is equivalent to 40 points (40%) and also that 0→100 in "Visual-permeability" is equivalent to 20 points (20%).

(Analyst) – Thank you. We have now the correspondent weights to these three criteria. But, as you know, "Visual Permeability" can be explained by three sub-criteria: "Visual-Contact"; "Depht-of-Views" and "Wide-Views". Using the same type of reasoning could you please tell me how do you rank them?

(DM) – For me it is very important that the city allows me to make visual contact with water. In second place I consider that the possibility of having wide perspectives is very interesting and finally, in third place, the depth of views over the river.

(Analyst) – So… you are saying that, in your opinion, the order is:

1st- Visual-Contact

2nd - Wide-Views

3rd - Depht-of-Views

(DM) – Yes … and I would say that … if the swing 0→100 in "Visual-Contact" means a value of 100 points then, I will say that the swing 0→100 in "Wide-Views" is equivalent to 70 points (70%) and also that 0→100 in "Depht-of-Views" is equivalent to 40 points (40%).

"Urban-Space-Quality" Criteria	w_i	w_i normalized
1st- Built-space-quality	100	62,5
2nd - Landmarks	40	25
3rd - Visual-permeability	20	12,5
Total	**160**	**100**
Visual Permeability :		
1st- Visual-Contact	100	48
2nd - Wide-Views	70	19
3rd - Depht-of-Views	40	33
Total	**210**	**100**

Table 1 – "Urban-Space-Quality" sub-criteria weights.

Using this procedure the all set of weights can be determined. Figure 7 represents the outcome to "Visual Permeability" of Jardas Stream in terms of its weighted profile.

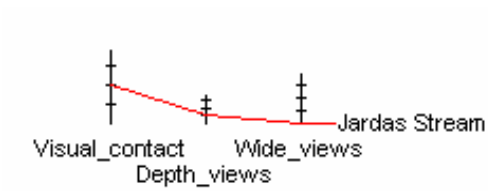

Figure 7 – The weighted profile for "Visual Permeability" of Jardas stream

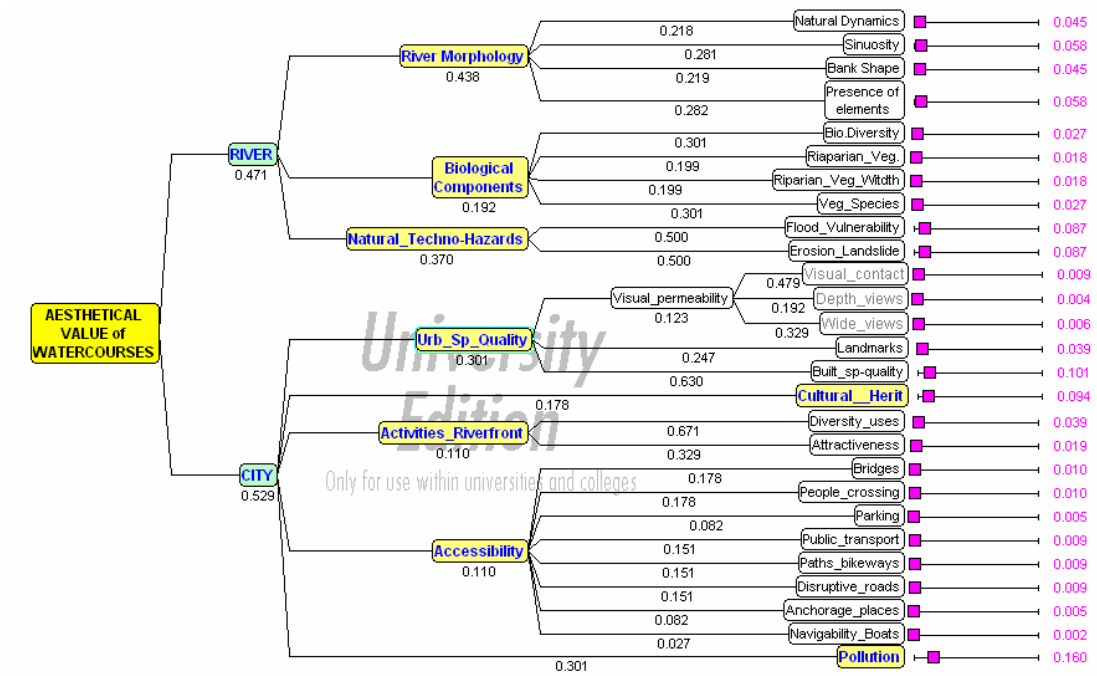

Figure 8 - A visual representation of weights, within each family of criteria and across tree, using VISA.

It is advisable that these weights can be discussed within a Decision-Team in order to obtain some sort of consensus about the case-study that is being evaluated.

6. Concluding Remarks

It is not possible to make an absolute evaluation of European Urban Watercourses. They are influenced by ecologic characteristics of rivers, by social and cultural context and also by the dominant values of society in a given moment.

In order to overcome this constrains it is advisable to:

- define homogeneous regions, as much as possible, in terms of ecologic, social and cultural characteristics;
- not to use the outcome of the aggregation procedure as a "black box", meaning that the score profile, before eliciting weights and value functions, should always be visible due to their explanatory value.

In the case of assessing the potential of rehabilitation or in order to choose alternatives of rehabilitation projects, it is possible to use an additive aggregation multicriteria model when applied to a given river, where the preference system of DM involved would be more stable and more informed by a specific knowledge of

the situation. Some difficulties can arise, in terms of determining the inter and intra-criteria information, when the analyst intends to compare different performances of urban watercourses.

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