Analysing the Castellers network

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Abstract

The aim of this project is to analyse the complex network formed by "Casteller" crews[1], playing "Castells"[2] interactions over time, in order to extract interesting knowledge from it. From this analysis it is expected to find a correlation of the performance evolution over the time with the interactions network of crews (e.g. crews playing usually with better crews may lead crews to increase their performance faster than others).

In order to represent the information for performing the analysis, this paper presents a new temporal model approach representing the *Casteller crews* scenario.

Keywords: Complex network, "Castells", "Casteller" crew, Performance evolution, Temporal model

1. Problem statement and goals

"Castells", also known as "human towers", are one of Europe's most genuine and unique cultural displays. "Castells" are an excellent way of showcasing Catalonia to the world. Watching or taking part in a "castells" display is a thrilling experience that really highlights under a single project the individual and collective struggle for improvement, the effort involved in achieving a goal, the solidarity and spirit of cooperation between people of all ages, conditions and abilities. Moreover, on November the 16th 2010, UNESCO[3] approved the inscription of "castells" on the Representative List Of the Intangible Cultural Heritage of Humanity, giving then a universal recognition to this element (cccc).

1.1. Glossary

Since there is a huge register of concepts exclusively related to the "castells" field. In this section some important concepts are being described in order to provide an initial knowledge on the vocabulary used in this paper.

- "Human towers": is the official translation of "castells" to English (HumanTower). Therefore, derived words will also be translated this way.
  - "Human towers player" → "Casteller"
  - "Human tower" → "Castell"
  - "Human towers crews" → "Colles Castelleres"

1. Group of people forming a team that plays "Castells".
2. "Castells", or human towers, are one of Europe's most genuine and unique cultural displays.
3. United Nations Educational, Scientific and Cultural Organization

- "Crown" a human tower: Once the "castell" is raised, a member of the crew (typically a small boy or girl) has to put his hand up at the top of the structure.
- "Unloaded" human tower: After being crowned, it is dismantled stage by stage until the "ground layers"[4]. In order to be considered a correct "unloading" it must be done in an ordered way (e.g. without jumping several layers at once).
- "Loaded" human tower: During the "unloading" process, the human tower falls before reaching the "ground layers".
- "Tried" human tower: During "loading" process (before the "crowning") the human tower falls.
- "Unloaded-trial" human tower: The crew is able to perform the "unloading" process, however the "crowning" was not performed. This last one reefers to a successful withdrawing, usually performed in order to avoid falling.
- "Gamma extra" (GE) human towers: Although, the human towers are usually considered by layers (e.g. human towers of six layers, of seven layers, etc.), the most difficult constructions are considered as an individual group named "gamma extra".
- "Pillar": The pillars are within the human towers set of constructions, however they receive a differentiated special treatment when being performed, and, moreover their "value" is never correlated with the rest of human towers of the group they belong to (e.g. pillar of four layers, corresponds to the human towers of six layers and the pillar of six layers corresponds to the human towers of eight layers).
- "La Coordinadora de Colles Castelleres de Catalunya" ("CCCC"): The CCCC is the organisation responsible of: looking after the human towers crews shared interests, promoting the human towers, guaranteeing the methodology correctness (e.g. secure measures) of the human towers performances and that the risks are properly covered by adequate insurances.
- "Concurs": Human towers crews, each year, are ranked according to the difficulty on the human towers they performed, within the current year. Moreover, there is each two years a one day special competition, named "Concurs", where all human towers crews play together in Tarragona city (see ConcursCastells). For this competition, they decide how to evaluate the human tower performances. This metrics decided become the official new metrics for the human towers evaluation.

The points table produced for the 26th "Concurs de Castells" edition (2016) has been added to the appendix A, as 2, of this paper, since it has been widely used in this project.

4. depending on height of the human tower, the "ground layers" may differ (see ?)

1.2. Motivation

From this description on the target scenario where this paper is focused. It might be straight forward to grasp some of the main ideas that have motivated this project. Some of these motivations are listed bellow:

- The target scenario can be represented very easily as a network of crews interaction, since the information of performances has been recorded and is public.
- The network is representing currently real data.
- This scenario has not been analysed from this perspective before.
- The data gathered for this project might be useful for further researches and studies on the field.
- The topic is a very important culturally representative characteristic of the local area, moreover also internationally recognised as an very valuable cultural tradition.
- Publicising local data as possible sources for high academic studies, rather than using research famous datasets. Which should be intended to serve for testing new methods, since all their properties are already well known, however are of none interest when using well known methods, without any aim rather than learning the applied methods characteristics.

1.3. The target scenario

During the last decades “casteller” crews have shown an exponential growth (i.e. increase in number of performances, people participation and number of crews).

Figure 1 shows the number of human towers performed per year, during the last decades, all performance trials are quantified in this plot (i.e. each bar in the plot represents the number of all *unloaded*, *loaded*, *tried* and *unloaded-trial* human towers, that toke place in the a certain year, which are added together and plotted). From it, it can be observed three different periods of growth:

1. **The First raise (from 1991 to 2002):**

   “Castells” gain popularity and many new crews are created.

2. **The depression (from 2003 to 2009):**

   The number of performances per year, starts to decrease.

3. **The platinum period (from 2010 to 2015):**

   Many factors are given that benefit the “castells” popularity again to arise (e.g. the economical crisis, the university “castells” crews growth and the climbing fashion), reaching its best historical moment (this current year 2016 it continues increasing).

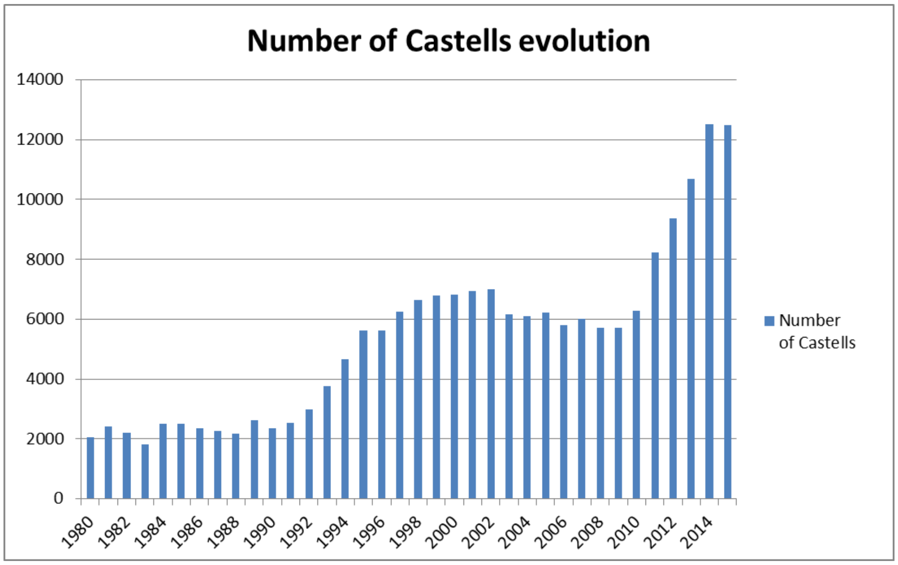


Figure 1: Human towers number of performances evolution over time.

This increase in number of performances given by an increment in number of participants on the existing crews and the creation of many new crews. This increment on the number of participants provided the means to many crews to grow and reach the last levels of performance, where many members are needed for the performances.

1.4. Contents

In section 2 all related work found, previous analysis and literature regarding the human towers topic, is reviewed, providing an overview on the existing knowledge surrounding this project. Section 3 presents the new dataset created of the *Castells crews* activity, used in this paper. In section 4 the model designed for representing the analysed information is widely discussed. In section 5 the analysis strategies selection process is illustrated, while commenting on the results of the different alternatives proposed. Section 6 presents the discussion on the results obtained from the analysis performed in section 5. In section 7 the possible extensions of this project, together with the strengths and weaknesses analysis of the execution are commented. In section 8 the conclusions obtained from the project are discussed. Finally, additional information regarding the project can be reviewed in the Appendix (A, B and C).

2. Related work

There exist few “serious” (using enough data to be representative and sophisticated statistical methods, rather than just averaging over the results, or retrieving the percentages counted) studies performed within the human towers topic.

After researching exhaustively for related literature concerning other studies performed within the human towers topic, some interesting articles and web sources were found.

In the following part of this section these references are listed and commented.

Articles

- "El risc dels castells"(CCCC, 2011): presents a discussion on the risks of playing human towers.
- "Incidència de lesions en els infants de les colles castelleres de Catalunya"(Pere Godoy und Urtxuletegui, 2011): presents a comparison study on the children injuries, suffered by playing human towers, compared to children who play other sports.
- "Projecte d'estudi de la necessitat, implantació i efectivitat del casc per al pom de dalt"(Rosset und Rovira, 2012): presents a study on the needs for introducing the helmet usasge for the highest positions of the human towers.
- "Les colles castelleres: unes organitzacions singulars"(Botella und Navalpotro, 1998): presents a study on the human and economic resources, and the organisation of human towers players associations.
- "Riesgo de lesión en los castellers a partir del cálculo de la energía potencial"(Jaume Roset Llobet und Orfila, 1997): presents a study on the theoretical injure risk of human towers players considering the potential energy they acquire when climbing the human towers.

Web sources

- "Base de Dades de la Coordinadora de Colles Castelleres de Catalunya – Colla Jove Xiquets de Tarragona"(BDCJ): is the official historical register of all human towers played since 1926.
- "Portal Casteller"(portal): presents a set of interesting statistical tools and direct access to the BDCJ(BDCJ).
- "Ciència i Castells"(cienciaicastells): shows diverse studies performed related to the human towers topic.
- "Viquipèdia-Castells"(viquipedia): actually, is the most complete and updated documentation source referring to the human towers (e.g. human towers history, description of each human tower and human tower crews, are some of the many subtopics documented in viquipedia).

As can be observed from the listed sources above, almost all the studies performed within the human towers topic are related to risk and injuries caused by playing human towers. Thus, it was not possible to consider any previous work related to the aim of this project.

3. The dataset

In order to build the model, the first action to take was to search for all possible data needed, in order to build a reasonable model. Thus, ensuring the utility of the designed model, since the data was already gathered.

For this project a new dataset was created, which collects all the performances activity of the human towers crews from 1990 to 2015.

In order to gather the data for creating the dataset, it was necessary to contact BDCJ and (portal) admins. Which facilitated the data access.

3.1. Format and information

The information is stored as plain text, where each row corresponds to the results from one crew in an specific event. When interpreted in matrix format, columns are separated by the character #, and correspond to the following information:

1. Date (in format: *dd/mm/yyyy*).
2. Location (city name).
3. Name of the event (events where crews play, usually correspond to local festivities).
4. Name of the crew.
5. Record of activity within this event (all trials are recorded, also the unsuccessful ones).

The information regarding the *university crews*[5], which play on a different league, was removed, in order to preserve only relevant information.

The dataset contains all events results recorded within the period from 01/01/1990 to 31/12/2015, accumulation a total of 33314 instances.

4. The model

The aim of this section is to provide a clear understanding on the strategies designed for modelling the target scenario.

The target of this paper is to analyse the possible correlation between the human towers crews interaction, with their performance evolution over time, by modelling this scenario using a complex network representation.

The elements and relations that are necessary to be fitted in the model are the following:

- Human towers crews
- The performance “level” of the crews (i.e. how good they are)

5. Human towers crews which only play within a university league, but are not able to play with common crews.

- The “growth” index of the crews (i.e. how their performance level changes over time)
- The “unsafeness” index of the crews (i.e. how their unsafeness level changes over time)
- How crews are related to each other
- Time dependence (e.g. two crews that played 20 times in one certain year, they will still be related the next year, even if there are none events where they play together that year)

In order of being able to analyse the mentioned scenario it is necessary to define a model of these elements and interactions.

The first approach designed for the model was modelling these interactions is performed by a weighted graph representation, where each node represents a human towers crew and edges represent playing-together relationships between crews.

Although this proposal was able to represent in a proper way many of the elements required, the relations between where uninteresting, since almost all crews where related.

In order to obtain a highly representative and expressive model, the modelling process was repeated several times, in order to obtain the most suitable representation possible for performing all the desired analysis.

Finally, the approach presented in this paper was achieved. Next the general features of this model are commented.

4.1. Model design

As has already been stated, the complex network model representation was decided to be a *directed*[6] *weighted*[7] graph.

In order to represent the temporal evolution, it was decided to build an independent network for each season, whereas using the previous network information when building the new one. Thus, having a model representing current information with temporal smoothing. Moreover, maintaining an historical record of the previous networks, to be used in the analysis.

The network main elements, and their main properties, are the following:

- Nodes → Human towers crews

  Each node should maintain the following information concerning the crew represented:

  - *Performance level*
  - Growth index
  - Unsafeness index

6. Edges, which indicates the connectivity between two nodes, are unidirectional.
7. Edges have weights associated, which indicate the grade of relation between nodes.

- Edges → relation between pairs of crews

  Each edge should maintain the following information:

  - *Grade of relation*
  - Type of relation
  - Direction of the relation

Some of the concepts introduced in the model have been designed for modelling the scenario in the most suitable way for solving the target analysis problem.

The following part of this section presents a discussion on the, most critical, of the mentioned new concepts (which are shown in cursive in the previous list) and different possible approaches for improving the initial design of the model.

4.2. Grade of relation

The calculation of the grade of relation between two crews was decided considering the following ideas:

1. Two crews become to be related only if they have played a minimum amount of times together within a year.
2. There should be an influence when playing several times with "similar"[8] crews.
3. Having performed several times with a crew the previous year, should still have an effect in the current one.
4. Having performed any number of times with a crew many years ago, should not have any significant influence on the current year (i.e. relations should degrade with time).
5. It is different to play several times with a crew of some level, than with another of higher level.
6. The influence of playing n times with a crew c_1 of level L_1, should be equivalent to playing n times with different crews of a subset of crews X', where

$$\forall x_i \in X' \quad level(x_i) = L_1$$

8. Crews from the same or similar "level"

4.3. Performance level

The calculation of the performance level of a human towers crew was decided considering the following ideas:

1. Time has been discretized in years (i.e. for each year, it will be computed from the collected results at the end of a that year).

   Although it might seam more logical to compute the level of a crew and use it on the following year, there are some important factors (e.g. crew leaders and crew members), regarding the human towers crews internal state, that might change from one year to the next one. Therefore, if considering the previous achievements, although the know how will be usually better represented, the influence from one crew to the other could not be not well captured if it has entered in a bad period.

2. The performance of a crew will be measured by the most complicated construction (i.e. human towers have a difficulty assigned (see ConcursCastells)) unloaded within a year, the punctuation considered for this report is shown in 2.

4.4. Extensions on the model

In this section there are commented some of the possible improvements to the proposed model that could support it to better represent the scenario described.

- Crews from a very similar level could be considered non-influencing crews over each other.
- However, the influence of playing with a crew which is "better", but during the play has only performed constructions which are not a challenge for the other participants, could be discarded.
- It would be interesting to build a second model representing triviality relations, which would be representing the influence on playing with crews of the same level. This fact, usually encourages crews to demonstrate that they are not inferior to other participants, by training harder and, perhaps, assuming more risks, in order to impress the public.
- Integrating the *know how* influence relations, within the same model than the *rivality* influence, would provide a more complete view on the scenario represented by the human towers crews.

4.5. The presented approach

In this section the final model implemented for this paper is described.

- **Overall** → historical record of temporal smoothed directed weighted graphs.

- **Time discretization** → seasons (i.e. correspond to natural years). The period modelled for this project was from 1990 to 2015. Notice that no temporal information will be used in the analysis phase, from the first season of the period (i.e. 1990). Since, the graph generated from it, is only aimed to be the initialisation seed of the full model building procedure.

- **Temporal representation** → temporal smoothing model. For every year there will be a model, which will be determined by the results of the current year, averaged with some the information of the previous one. Formally, for a certain season (year) s, the correspondent model, M_s, would be calculated as

$$M_s = (1 - \lambda)R_s + \lambda M_{s-1} \tag{1}$$

  , where R_s represents the raw results obtained on the evaluated season, s; λ is the *temporal smoothing factor*, which indicates the how much the previous model influences in the current one, and must maintain the property of that $0 \leq \lambda \leq 1$; and M_{s-1} referrers to the model of the previous season, $s - 1$.

  Notice that, the model calculation procedure is just a strictly positive weighted average between the information recorded from the previous seasons, with the new one. The decision of using the information of only, at most, the previous three seasons, is due to reduce the undesired outdated information influence.

- **Temporal effect** → the temporal effect is the relevance of the previous models accumulated in the current one. In the formulations presented in this paper, the temporal effect is represented by the *temporal smoothing factor*, which was introduces on the above formulation of the model calculation (4.5). This parameter is represented by the Greek letter λ. The value decided for this model was $\lambda = 0.5$, since the relevance of the previous season information model has much influence on the overall results obtained in the current one (e.g. the previous season results are likely to be relevant when determining the crews initial moral state and their goals).

- **Nodes** → crews.

  Notice that crews will not be represented if they have not been created yet, moreover, will stop appearing if they are dismantled.

- **Edges** → influence relations between crews.

  For the final model it was decided to incorporate the extension of the *rivality* relations. Thus, let both types of relations be described as:

  - **Know how relation** → representing the influence of a crew being able to learn from another, during an event that took place.
  - **Rivality relation** → representing the influence of a crew being in a situation where they would intend to outperform the results of another one. Thus, being able to learn by striving.

  Before continuing, let some special considerations be introduced:

- In order to introduce a new edge in the model, some requirements must be matched.
  * Requirements for the *know how* relations:
    1. The differences of *levels* between crews must be *significant*.

       Significant difference of levels: in the presented approach this functionality is solved by applying a weak lower threshold of value 3. So that a difference of levels, d, is considered to be significant if $d \geq 3$.
       Although, it is assumed that this assumption will introduce error in the model, since the high complexity of modelling the *know how* influence, after considering different alternatives, it was decided as a need to impose a strict threshold for avoiding generating simultaneously *know how* and *rivality* relations, for a single interaction.

    2. Among constructions performed by the crew with higher level, there must be, at least one, *interesting construction* to the other crew.

       Interesting construction: in the presented approach this functionality is solved by applying a weak lower threshold of value 2 to the two *top human towers* of the crew with lower level.

       Top human towers: are the most difficult human towers *loaded* by crew, within a certain season.

       Thus, searching the 2 most difficult constructions "loaded" by the crew within the season, for which the analysed event took place. And then checking if among the "unloaded" human towers, of the crew with higher level, there is at least a human tower as difficult as the second most difficult human tower "loaded" by the crew with lower level, within the season evaluated.

    Only when all the stated requirements are fulfilled, then the interaction among the analysed crews will be quantified as a *know how* relation, and represented in the model.

  * Requirements for the *rivality* relations:
    1. The differences of *levels* between crews must be *irrelevant*.

       Irrelevant difference of levels: in the presented approach this functionality is solved by applying a strong upper threshold of value 3. So that a difference of levels, d, is considered to be irrelevant if $d < 3$.
       Although, it is assumed that this assumption will introduce error in the model, since the high complexity of modelling the *rivality* influence, after considering different alternatives, it was decided as a need to impose a strict threshold for avoiding generating simultaneously *know how* and

rivality relations, for a single interaction.

2. Among constructions performed by each of both crews, there must be at least one the 5 self *top trials*, of the respective crews, in the evaluated season.

   Top trials: most difficult constructions tried within a season by a certain crew (whether there where finally achieved or not). It is used for representing the target level of a crew within a season.

   Thus, having that each of both crews must have tried to perform at least one of their lists of five *top trials* of the current season.

3. Finally, within the event, there must exists a clear rivality situation. In this model, the rivality situation is considered to exists when the following situation takes place: Let a certain crew a be playing together with b, and all the previous requirements be fulfilled. Next let us assume that a was the crew who *loaded* the most difficult human tower, h, in the analysed event, e, comparing the constructions *loaded* from a and b. Then, only if crew b tried to build a human tower, at least as difficult as h, this interaction will be considered as a *rivality* relation, otherwise it will be discarded.

– It is considered that two crews can not be related by both types of relations in the same model for a given season, s. Thus, if a pair of crews show to have a relation of any type, when calculating the average of all features, only previous information of the same type will be accumulated in the new model. Formally, when calculating the model for season s, M_s the weight of an edge e_s, w_{e_s}, which in the new results relates nodes a and b, such that $e_s = \{a, b\}$, will be calculated as

$$w_{e_s} = (1-\lambda)e_{s_w} + \lambda \begin{cases} 0 & \text{when } \nexists\ e_{s-1} \in M_{s-1_{edges}} \text{ so that } e_{s-1} = \{a,b\}, \\ 0 & \text{when } \exists\ e_{s-1} = \{a,b\}, \text{ but, } e_{s-1_{type}} \neq e_{s_{type}}, \\ e_{s-1_w} & \text{when } \exists\ e_{s-1} = \{a,b\} \text{ and } e_{s-1_{type}} = e_{s_{type}} \end{cases} \tag{2}$$

Therefore, there exists two different types of edges of influence, which will be represented separately. However, the weights of both types of relations are calculated the same way. Since, it was decided to just use the number of relations that toke place during a season as the new results which have to be averaged by means of equation (4.5).

- **Weights** $\rightarrow$ degree of relation between crews.

  Let $A^s = a_1, a_2, ..., a_n$ be the total set of human towers play events registered within a season s. Recall: each play event a_i has the following properties:

– Date
– Location
– Event name
– Participant crews
– Human towers results per crew

Next the way how the events are selected as part of the represented relations by the model is recalled. Moreover, from the subset of relations of each of both types, rivality or know how, the weight of the edge will be calculated using the same equation (4.5), with the extension of equation (4.5).

– Know how influence: Next, let $A^{s\prime}$ be a subset of A^s containing only the performances where a certain pair of crews, x and y, being x a crew with a "significant higher level" than y, in the season s. Finally, $A^{s\prime\prime}$ is obtained as the subset of $A^{s\prime}$ accomplishing that the Human towers unloaded by x were of "interest" for the crew y, in the evaluated season, s.
– Rivality influence: The rivality influence weight is calculated by means of the same procedure, but changing the criteria to obtain the subset. In this case the steps for obtaining the subset $B^{b\prime\prime}$ are the following: first let $B^{s\prime}$ be a subset of A^s containing only the performances where a pair of crews x and y, being x a crew with an "equivalent" level than the level of y, in the season s. Next, $B^{s\prime\prime}$ is obtained as the subset of $B^{s\prime}$ accomplishing the statements presented in the above descriptions, when regarding the description of the *rivality* relations insights.

Formally, from the subset $A^{s\prime\prime}$ (named $B^{s\prime\prime}$ in the upper description, but being essentially the same concept) the weight of relation $\{y, x\}$ is calculated as defined in equation (4.5), where e_{s_w} is calculated as

$$e_{s_w} = \left|A^{s\prime\prime}\right| \tag{3}$$

, notice that e_{s_w} is calculated just by means of counting the number of relations between the two crews (nodes), for a certain season s.
Formally the global equation for calculating the weight of an edge when having, a priory obtained, the subset $A^{s\prime\prime}$, can be written as

$$w_{e_s} = (1-\lambda)\left|A^{s\prime\prime}\right| + \lambda \begin{cases} 0 & \text{when } \nexists\, e_{s-1} \in M_{s-1_{edges}} \text{ so that } e_{s-1} = \{a, b\}, \\ 0 & \text{when } \exists\, e_{s-1} = \{a, b\}, \text{ but, } e_{s-1_{type}} \neq e_{s_{type}}, \\ e_{s-1_w} & \text{when } \exists\, e_{s-1} = \{a, b\} \text{ and } e_{s-1_{type}} = e_{s_{type}} \end{cases} \tag{4}$$

As can be observed, weights temporal effects fade rapidly. In order to avoid having deprecated relations, since up to this point edges never disappear, a threshold of minimum relation among two nodes will be applied after updating all weights. Those edges maintaining a weight lower than the threshold will be removed from the current model. The threshold decides for maintaining an edge in the model was $w_{thld} = 0.3$ for both, the *know how* and the *rivality* relations.

- **Directions of "know how" influence** → only crews who have witnessed a crew with a "significantly higher level" performing a human tower of "their interest" (i.e. at least, as difficult as the most difficult human tower which has been achieved by them) are influenced by them.

  Moreover, the relation finally was decided to be defined as: "being influenced by the know how of" relation, thus, the direction of this relation will always be from the crew with lower level to the one with higher level.

- **Directions of "rivality" influence** → only crews who have witnessed a crew with an "equivalent" level (i.e. at least, as difficult as the most difficult human tower which has been achieved by them) are influenced by them.

  Moreover, the physical direction of the rivality edges is redundant, since rivality edges will always be symmetrical in both directions.

4.6. The Models Criteria

In this section the criteria mentioned to be represented by the described model is defined, together with the required subcriteria for building the model.

Recall: In this paper the criteria will be calculated as the average of the current results the previous season model, as was stated in equation (4.5), which corresponds to applying temporal smoothing to all the information represented by the model.

Moreover, for facilitating the reading, in the criteria formulations drawn in this section, the temporal smoothing is omitted, however, notice that in the real equations implementation it will always appear with the form $C_s = (1-\lambda)R_s + \lambda C_{s-1}$, which is just applying equation (4.5) to the criteria final calculations.

4.6.1. Subcriteria

Before going further let some *subcriteria* be defined.

Level/difficulty of a human tower: During the previous sections, in several occasions it was mentioned to compare human towers difficulty or value.

In this paper the method for evaluating the numerical value, which is proportional to the difficulty, of a human tower, the strategy proposed is to use the row number of table 2, where the human tower appears, if it does. Otherwise the value, $V(ht)$, of the construction, ht, will be defaulted to zero. Let this strategy be formalised as

$$V(ht) = ROW(ht) \tag{5}$$

, where function $ROW(x)$ returns the row index associated to a human tower x in table 2, when it appears on it, and zero as default, otherwise.

4.6.2. Criteria

In the following part of this section the different criteria considered for this paper are discussed.

- **Crew level:** Let a represent any crew of the alternatives set A, then the *level* of crew a in season s, is computed as the *row* of table 2 corresponding to the most valuable (i.e. more difficult) human tower, *unloaded* by the crew a within the season s. Formally, can be written as

$$level(a_s) = V(a_{s_{ht_{top}}}) \tag{6}$$

, where $a_{s_{ht_{top}}}$ is the most difficult human tower unloaded by the crew a during season s.

- **Growth index:**

Measures the progression of the crew as the increment in new more difficult constructions unloaded per season.

Notice that this factor may be negative in some cases (e.g. when having the best performance of a certain season being lower rated, than the previous ones).

Formally, the *Growth index* of any crew, a, of the total evaluated set, A, in the current season, s, is calculated as

$$G(a_s) = level(a_s) - level(a_{s-1}) \tag{7}$$

- **Unsafeness index:**

Calculated as a percentage of falls using the information of the current season. In fact is calculated as addition of all the falling rates computed from the overall trials of a crew in a certain season, divided by the number of unloaded human towers in the same season. The division is introduced in order to smooth the result an leave it in a more expressive scale, which relates successfully and unsuccessfully performances of the analysed crew. Formally, the unsafeness index, U, of a certain crew, a, in a given season, s, can be written as

$$U(a_s) = \frac{\sum_{j=1}^{m} F(a_s, a_{s_{t_j}})}{n}$$
$$\forall r_{ij} \in a_{s_t} = \{a_{s_{t_1}}, a_{s_{t_2}}, ..., a_{s_{t_m}}\} \tag{8}$$

, where m is the total number of trials performed by crew a during season s; n is total number of unloaded human towers within the same season, ensuring then the property that $m \geq n$; a_{s_t} corresponds o any trial performed by crew a during season s; and the function $F(a_s, x)$ is defined as

$$F(a_s, x) = \begin{cases} 0 & \text{when trial } x \text{ did not fall,} \\ 2^{D(a_s,x)} & \text{when trial } x \text{ did fall} \end{cases} \tag{9}$$

, being $D(a_s, x)$ the maximum of: 0; and the distance between the trial x and the level of the evaluated crew, a, in the evaluated season, s. Formally, $D(a_s, x)$ is defined as

$$D(a_s, x) = max(0, V(x) - level(a_s)) \tag{10}$$

Notice that a crew falling from a human tower of a higher *row* position in the table, than their *level* (i.e. their maximum unloaded within that season, see (4.6.2)), can be severely penalised. This measure has been designed to punish crews trying to perform constructions without a progressive notion, and demonstrating that actually they were not well enough prepared for their quests (which, in fact, would lead them to success, not only omitting this penalisation, but increasing many other positive criteria).

Next an example is exposed: A certain crew x has a level of 5 in season 2016 (row 5 corresponds to *3d7* in table 2, thus this is the most difficult construction unloaded in season 2015). Since they have this human tower "dominated" (i.e. unloaded several times), without training much, they intend to perform the *3d8* (which corresponds to row 17 in table 2). Their argument is that "you *physically* only need three people more and they have three substitute players that were able to take part in the *3d7* human tower". In this case, the penalisation when falling and not unloading this human tower within the same season, would be calculated as: 2^d, where $d = dist(3d8, 3d7) = 12$, so each fall from the *3d8* would be equivalent to falling 4096 times from the *3d7* (falling n times from the *3d7* would be calculated as $2^0 \times n$, while falling n times from the *3d8* is calculated as $2^12 \times n$).
This reasoning may seem exaggerated, but in fact, in this paper states it is considered that there is not sensible to consider the safeness of a crew which fell "apparently" intending to fall. As a crew, involving people, belonging to a crew, in unreasonable quests, will bring dramatic impacts to the unsafeness criteria calculation. Whereas, falling with low frequency from reasonable trials, will retrieve the best (minimal) results. Thus, failures should be reasonable regarding crews *level*.

Notice that, since the equation normalises the falling rates sum by dividing by the number of unloaded human towers within the season, which usually is a large number, and after all the temporal smoothing is applied, at the end the impact of this, somehow, exaggerated rating strategy is scaled to more interpretable scores.

4.7. Model visualisation

This section explains the plots generated from the model, and how the information is represented on them.

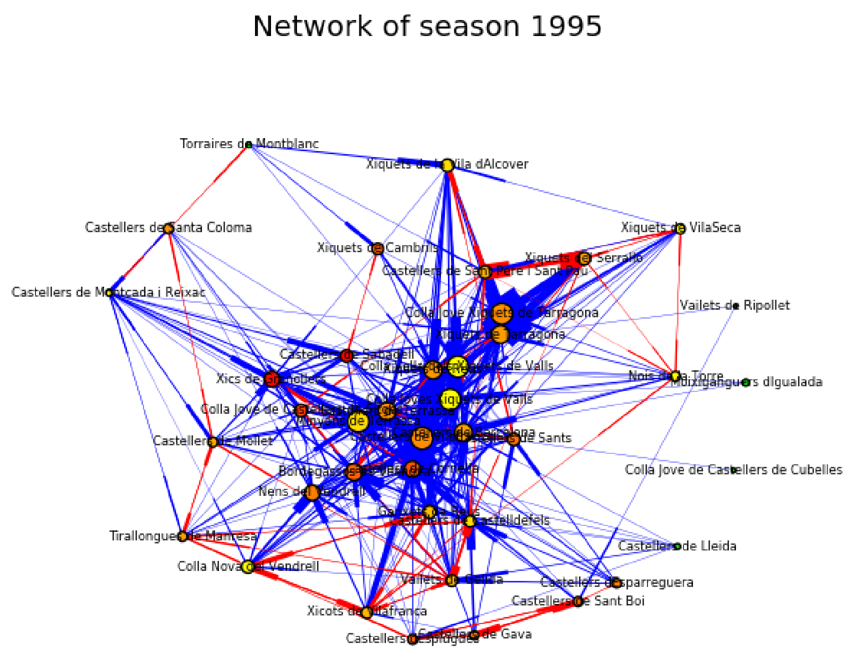


Figure 2: Submodel representing the models information for season 1995.

Figure 2 illustrates the visualisation of the network representing the interaction between *Casteller* crews, that took place within the season of 1995. This network, is one of the networks forming the global model, which is composed by an assemble of submodels, like the one illustrated in the mentioned figure.

The information represented in figure 2 is more than just the relations between crews, as can be noticed by the different colors appearing on it.

Let the information being shown in the submodel figures be described in the following part of this section.

- Blue arrows → *know how* relations
- Red arrows → *rivality* relations
- Width of the arrows → weight of the relations
- Nodes of the network → *Casteller* crews
- Words associated to the nodes → names of the crews

- Size of the nodes → level of the crews
- Color of nodes, when GREEN → new crews
- Color of the nodes (non-green) → growth index of the crews (i.e. LOW → HIGH)

In order to provide a complete insight view on the model generated, the full set of seasons submodels can be reviewed in the Appendix B, at the end of this paper.

5. Analysis

In this section the analysis strategies proposed for the knowledge extraction process, on the temporal model designed, are presented and discussed.

The presented model is formed by the collection of the weighted directed graphs, one for each season evaluated. Which are build from the information collected during the evaluated season, averaged with the information of the graph representing the previous season. Thus, the model represents in a robust way, due to the temporal smoothing, the state of the *Castells crews* scenario, for each of the evaluated years.

Several analysis could be interesting to be applied to the model described. However, the analysis should be focused on the aim of the paper.
Recall: The aim of this paper is finding underlying correlations between the *out degrees*[9] of the nodes and the *growth index* criteria (i.e. finding the correlation between *play-with* relations and the performance evolution of *Casteller crews*).

Once having the model built, before starting to design any analysis, a good methodology is to perform a basic analysis of the generated network, and extract the general properties of it. This pre-analysis, could help to discover some interesting properties of it, while checking if the model corresponds was correctly assembled.

Thus, before gowning further let the pre-analysis considered in this paper be discussed.

5.1. Pre-analysis

The generic analysis considered where the following:

- **Degree distribution analysis:** consists on searching for properties and tendencies underlying in the networks degree distribution. As outcome may conclude if the network is of one of the well known generic existing networks.
- **Community detection analysis:** will retrieve the communities existing in the generated network. While drawing interesting information concerning the connectedness between them and general topology of the network.

9. Sum of the weights of the edges which are connecting a certain node, with its neighbours.

From the two pre-analysis strategies considered, it was decided to perform the degree distribution analysis, since analysing the overall properties of the degree distribution could provide some hints on how to design the specific analysis for facing the goals of this paper. Whereas the community analysis was discarded, since the specific information concerning how the individual crews are connected is not of interest within the scope of this paper, moreover, the interest relies on extracting general knowledge, rather than analysing which crews are more connected to each other.

5.1.1. Degree distribution analysis

The analysis implemented for this pre-analysis strategy are commented in this section, together with some comments on the results retrieved.

Analysis description:

1. Compute the degree distribution using histograms in log scale
2. Compute the degree distribution
3. Compute the complementary cumulative degree distribution
4. Fitting of the power-law exponent from the histograms
5. Fitting the maximum likelihood estimation (MLE)
6. Examine the results from all the previous steps and search for correlations with the known characteristics of the following types of networks:
   - Random networks → when following Poisson degree distributions
   - Scale-free networks → when following power-law degree distributions
7. When sharing interesting properties with the mentioned network types, continue the analysis applying further techniques (e.g. check if the network follows the "preferential attachment model").

However, after applying the described methods, the conclusions drawn from the results retrieved where that the networks integrating the model, did not follow any of the mentioned characteristics. Thus, it could not be ensured if the results form the degree distribution analysis, were of any interest for accomplishing the objectives of this paper or not.

After deeply analysing the mentioned results, it was noticed that although the results had an overall main tendency, from every single network integrating the full model, different results could be driven.

Therefore it was decided to perform a slightly different version of the analysis strategy, which is discussed in the remaining part of this section.

The main change was to consider that the analysis conclusions should be driven in the complete model, rather than taking only into consideration the individual submodels integrating it, separately.

Thus, the information from the degree distribution of the full temporal model, which was composed by 25 networks, was collected and analysed as if forming part of a single network.

This alternative to the traditional approach had some additional benefits rather the single representation and aiding the possibility of extracting knowledge from full model directly.

- Notice that the number of nodes in each of the networks composing the full model, are never more than 100. Thus, analysing this networks separately will surely lead to weak conclusions, in many cases, based in outliers of the overall model.
- Thus, by means of adding the information in a unique analysis, will increase the data considered, providing more robust results on the characteristics of the degree distribution being considered.

However, after applying this second approach of the analysis, although the results obtained where clearly more expressive in all experiments, the conclusions where still negative with respect to matching the generated model to the characteristics mentioned of the known generic networks commented.

In order to provide a more complete understanding on the procedures and decisions taken within this project, the results form the second approach of the pre-analysis procedure can be reviewed in the Appendix C, in section C.1, at the end of this paper.

5.2. Analysis design

From the *pre-analysis* strategies implemented it was possible to extract the following knowledge:

- Several nodes of the networks had degree 0
- The degree distribution did follow the principle of that there where lower nodes of higher degrees rather than nodes with lower degrees.
- The built model would not be properly emulated by any of the considered networks generation models:
  - Erdös-Rényi (ER) $\rightarrow$ random networks ($G(N, p)$ model)
  - Configuration Model (CM) $\rightarrow$ scale-free networks (power-law distribution)
  - Barabási-Albert (BA) $\rightarrow$ incremental networks (preferential attachment method)

  The mentioned models were implemented and tested following the algorithms in the literature reviewed (Newman (2003), Boccaletti u. a. (2006) and Clauset u. a. (2009)).

- When fitting the MLE calculated or the power-law exponent, the results achieved had large error rates. Thus, the degree distribution did not follow the properties for being correctly regressed by this techniques.

Recall: The aims of the analysis of the model were the following:

Correlating the performance of crews with the different relations between them.

Thus, this goal may be subdivided in the following:

1. Finding correlations between growth index and degree of overall interactions of crews.
2. Finding correlations between growth index and degree of know how interactions of crews.
3. Finding correlations between growth index and degree of rivality interactions of crews.
4. Finding correlations between unsafeness index and degree of overall interactions of crews.
5. Finding correlations between unsafeness index and degree of know how interactions of crews.
6. Finding correlations between unsafeness index and degree of rivality interactions of crews.

Next the analysis strategies selection procedure is discussed.

1. The initial approach for the design was to treat the networks individually, as in the *pre-analysis* stage. However, the sparsity on the results was difficulting the process of extracting conclusions on the overall results. Moreover, in most cases, the results where driven from non significant amount of data.

2. In order to reduce the influence of individual instances present in the dataset, it was decided to use the same strategy mentioned, and taking at once the overall temporal model for performing the analysis.

3. Due to the number of points being plotted in the results, it was difficult to interpret the overall tendencies of the data shown. Thus, it was decided to perform a discretization on the degrees axis.

4. However, the result of this analysis had very high variance and population standard deviation. Which indicated that the results where not representative of the evaluated data.

5. Finally, in order to search for more clear correlations between the performance evolution an the interaction among crews it was decided to eliminate the agnostic analysis strategy, which was considered up to the moment.

Notice that in the previous strategies commented, all the degrees where treated the same way, without any distinction on the crew or the season where the degree came from. And, since the results from the analysis had large sparsity, it was considered that it could the case that this was due to the temporal evolution on the relevance of the crews influence (e.g. perhaps before the Internet boom, crews where more isolated in terms of interaction, and playing with others could be more significant).

In table 1 the different configurations designed for the analysis are illustrated.

Before presenting the configurations of the analysis, let some concepts be introduced:

- **Overall period:** from season 1991 to 2015 (both included)

  The other time windows used correspond the ones described in 1.3.

- **Overall crews:** all crews appearing in the model.

- **Small crews:** crews whose level is at most *2d7* (corresponding to row 14 in table 2).

  In this batch of crews there will be the commonly named "crews of six" and "crews of seven" (notice that the names refer to the height of the human towers they build).

- **Medium crews:** crews whose level is at least as high as *4d8* and at most as *9d8* (corresponding to rows 15 and 28, respectively, in table 2).

  In this batch of crews there will be the commonly named "crews of eight" and "crews of nine" (notice that, again, the names refer to the height of the human towers they build).

- **Large crews:** crews whose level is at least *3d8s* (corresponding to row 29 in table 2).

  These crews are commonly known as "Gamma extra" crews.

In the following section 6 the results obtained from the experiments, which can be reviewed in 5.3 performed with the configurations exposed, in 1, are discussed.

5.3. Analysis results

After applying the analysis with the configurations presented in table 1, sixteen plot results where generated.

Next the global results plot is exposed and discussed.

Figure 3 illustrates the results retrieved from performing the analysis using all the model's data. As it can be observed, the interpretation of the data is not straight forward, due to the sparsity of it, which is represented by the SD[10] values shown.

10. standard deviation

		PARAMETERS	
	Criteria	PERIOD	CREWS LEVEL
CONF 1	Growth Unsafeness	Overall	Overall
CONF 2	Growth Unsafeness	Overall	Small
CONF 3	Growth Unsafeness	Overall	Medium
CONF 4	Growth Unsafeness	Overall	Large
CONF 5	Growth Unsafeness	First raise	Overall
CONF 6	Growth Unsafeness	First raise	Small
CONF 7	Growth Unsafeness	First raise	Medium
CONF 8	Growth Unsafeness	First raise	Large
CONF 9	Growth Unsafeness	The depression	Overall
CONF 10	Growth Unsafeness	The depression	Small
CONF 11	Growth Unsafeness	The depression	Medium
CONF 12	Growth Unsafeness	The depression	Large
CONF 13	Growth Unsafeness	Platinum period	Overall
CONF 14	Growth Unsafeness	Platinum period	Small
CONF 15	Growth Unsafeness	Platinum period	Medium
CONF 16	Growth Unsafeness	Platinum period	Large

CONFIGURATIONS

Table 1: Configurations of the first analysis performed.

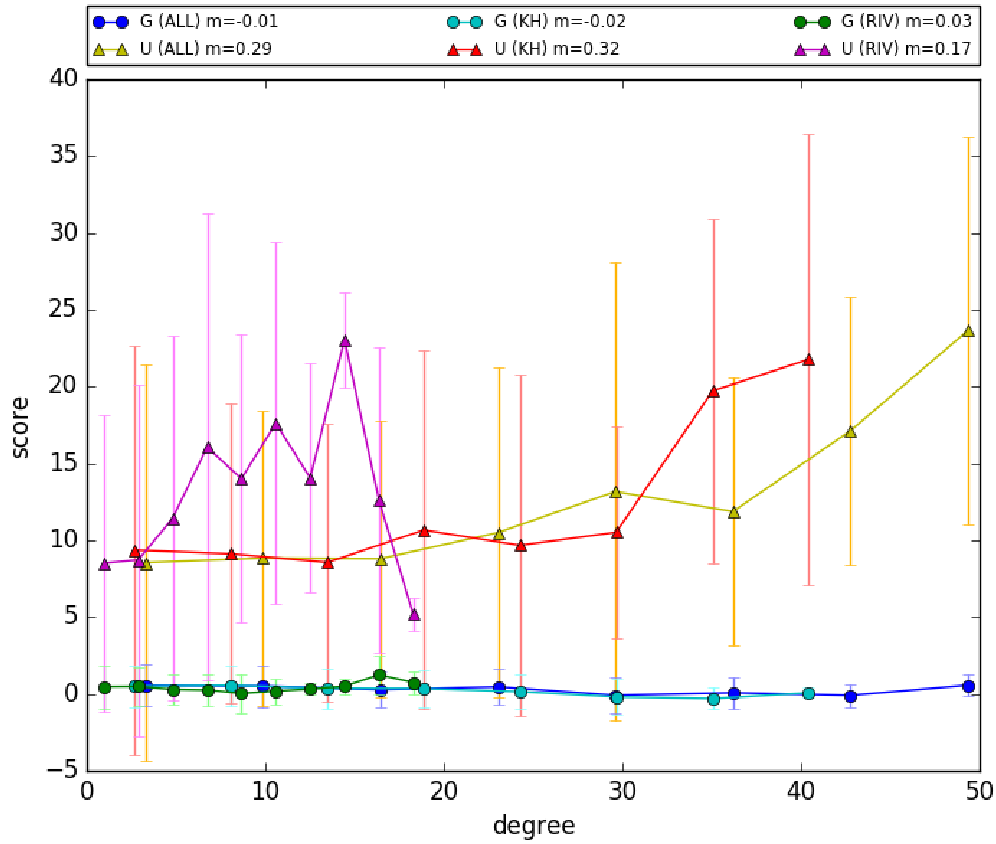


Figure 3: Criteria and degree correlating plot, representing all crews during the overall period.

5.3.1. Analysing the full model

By just analysing the information shown in figure 3, the initial conclusions that may be driven are the following:

1. While the *growth index* of crews does not seam to have a strong dependence on the degree, of any of both type of relations, neither in their joint model.

2. The *unsafeness index* shows an overall increasing tendency when degree increases.

However, as it has been previously stated, no strong conclusions may be driven from this data, due to the following aspects:

1. Sparsity on the results.

2. Dependence on the model correct design.

3. Lack of data when reaching high degree values.

Since, it was noticed during the experiments that in some cases, just two instances were used for plotting the result, in order to reinforce the correctness on the results (it be stated that it was restricted to be at least two instances for result shown, although being still weak results, it is necessary to retrieve results).

4. Dependence on the criteria design.

In order to support the analysis on the model, the partial analysis procedure presented in table 1 was also implemented.

5.3.2. Analysing the model in parts

After analysing the 16 results generated, as was already noticed when analysing the global model and, before, when performing the first analysis on the individual networks. It could be observed that in many cases the results generated where too poor to be properly interpreted. While in most of interpretable results, the conclusions extracted when analysing the global analysis where supported.

From the overall results retrieved in the analysis, it was decided to consider the most significant, those analysing the full period or the full crews set. Whereas, the discussion on the results obtained from analysing partial period and partial crews, at the same time, can be found in the Appendix C, in section C.2, at the end of this paper.

Next the most significant partial analysis results are exposed.

Overall period results

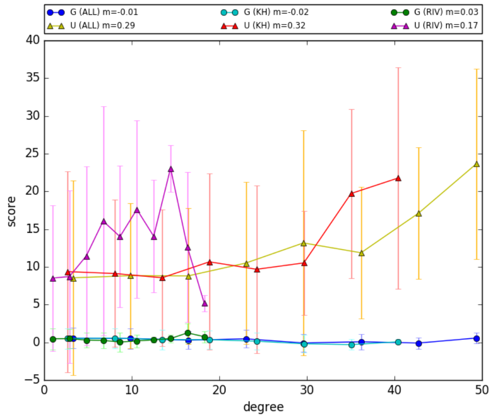
In figure 4 one can observe the different generated results from analysing the full period of time, taking for each analysis a different subset of the overall crews, selected by applying level thresholds.

Overall crews results

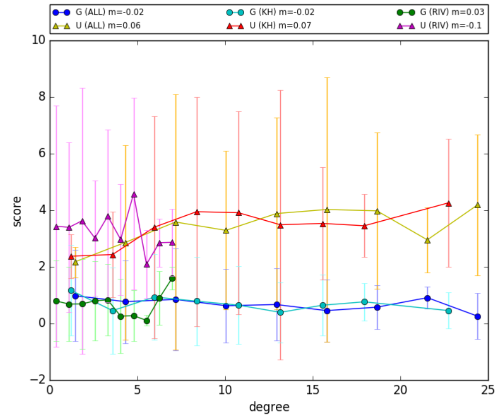
Whereas, in figure 5 one can observe the different generated results from analysing the full crews set, taking for each analysis a different subset of the overall seasons, selected by applying time thresholds.

The information representation metrics of the figures 4 and 5 is here described.

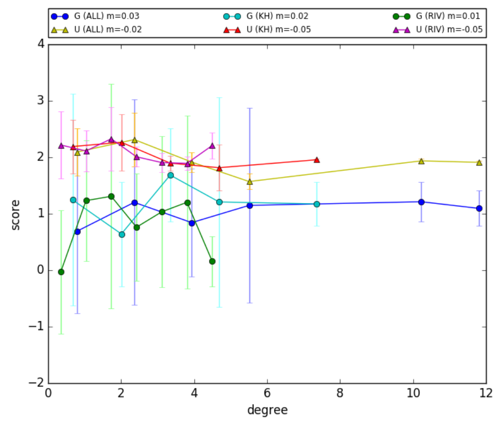
- Each line plot corresponds to a different, independent configuration.
- Line charts configuration is defined in the above legends, present in all figures.
- Each legend tag can be split in three parts:
    1. Symbol of the concrete line chart being referred.
    2. Letter which may be 'G'(growth index) or 'U'(unsafeness index). Thus, it refers to the criteria being represented.



(a) Results from *small* crews.



(b) Results from *medium* crews.

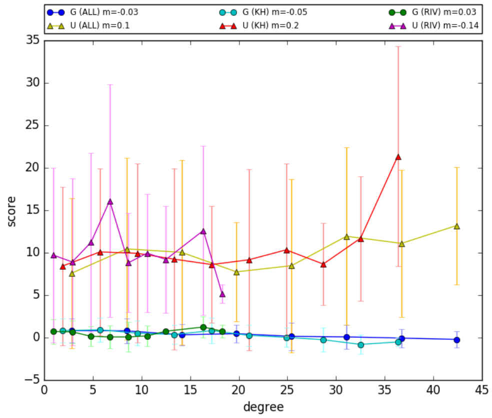


(c) Results from *large* crews.

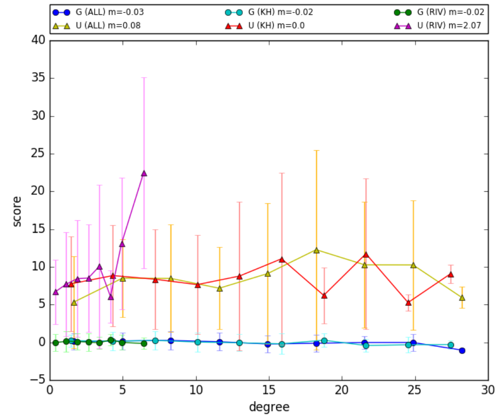
Figure 4: The above figures illustrate the results from analysing the full period of time, with different subsets of crews.

3. Some letters between brackets which can be the following:
   - ALL $\rightarrow$ all edges
   - KH $\rightarrow$ only *know how* edges
   - RIV $\rightarrow$ only *rivality* edges
4. Value, which refers to the slope of the the line chart drawn.
   From it will be easy to notice the overall tendency of the results.

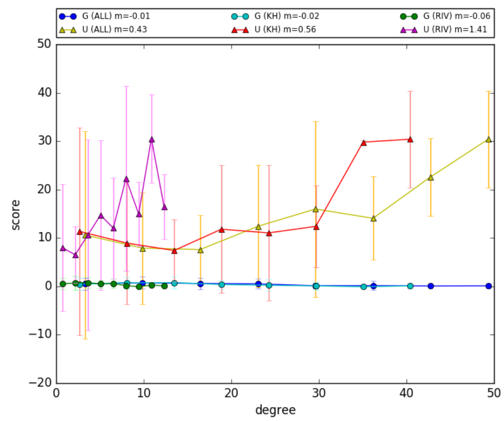
- Over each point forming the line charts, there is a vertical line of the same color (a bit faded), which indicates the SD measure calculated from the point calculation (average of individual results, having degrees of the same discrete cut).
- Moreover, notice the following general characteristics:
  1. Circles, as well as cold colors (blue, green and cyan), always refer to the *growth index* criteria



(a) Results from the *first raise* period.



(b) Results from the *depression* period.



(c) Results from the *platinum* period.

Figure 5: The above figures illustrate the results from analysing the full set of crews, during different periods of time.

2. While triangles and hot colors (red, yellow and magenta) refer to *unsafeness index*
3. In all plots the legend is identical, though it is only to notice which color corresponds to which information in order to interpret all results, or comparing them.

5.4. Extending the analysis

Before proceeding with the discussion on the results let the following considerations be discussed:

- The main aim of this paper was to find correlation between the growth index of crews to the interaction influence between them.

- However, although it seams logical to exists, this correlation was not possible to be inferred from the results retrieved, neither from any of the previous data representations tried during the analysis design process.

- The model build represents much more information than the used in the previous analysis presented.

From the stated ideas, it was decided to design a simplified analysis aimed directly to find correlations to the *growth index*, although not being directly related with the interaction between crews.

The second analysis procedure is composed by the following steps:

1. From each season representation in the overall model, select the following:
   - 10 crews with highest *growth index* value
   - 10 crews with lowest *growth index* value
   - 10 crews with highest *unsafeness index* value
   - 10 crews with lowest *unsafeness index* value

2. For each of both cases (the growth and unsafeness) data, build a representation plot showing the following information:
   - Level of the selected crews
   - The complementary information (in the case of the growth index, the complementary is the unsafeness index, and viceversa)
   - The degree of the interactions with the nodes neighbours

5.4.1. Results of the second analysis

In the figures forming 6, one can observe the different generated results from of correlating the growth and unsafeness criteria, to other information represented in the model.

Notice that this analysis was performed only on the global model, which implements both types of considered relations (*know how* and also *rivality*). Thus, the information regarding the relations being considered is omitted, since it will always consider both types simultaneously.

The information representation metrics of the figures in 6 is here described.

- Each line plot corresponds to a different, independent configuration.

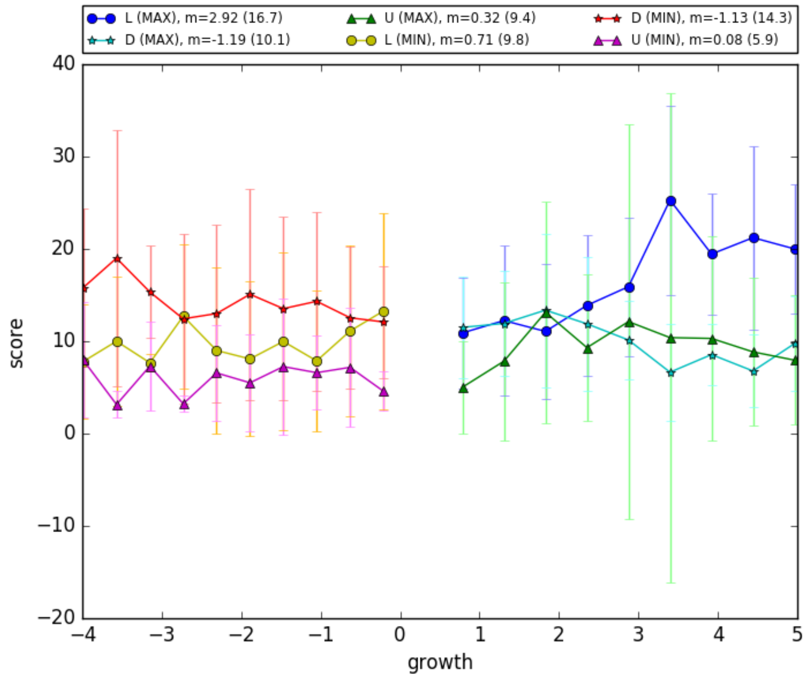
- Line charts configuration is defined in the above legends, present in all figures.

- However, in this case both figures are slightly differed in essence. Notice that figure 6a, has *growth* as x-axis, while that figure 6b has *unsafeness*.

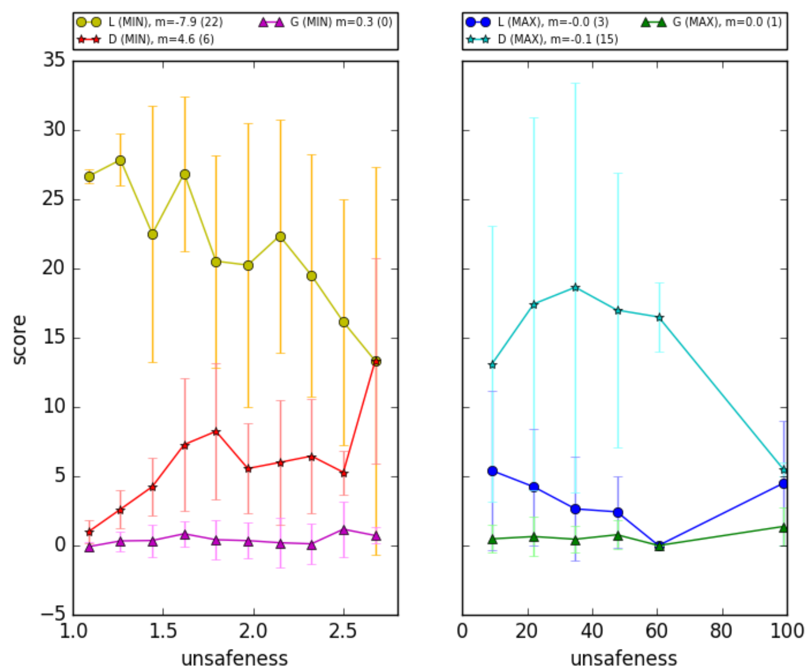
Due to this difference, let the neutral concept of complementary criteria, which will refer to the one of both which is not the one used for the x-axis, respectively in each both cases. By using this concept it will be possible to provide a general description on the visualisation features, and information representation metrics, of both figures at once.

- Each legend tag can be split in four parts:
  1. Symbol of the concrete line chart being referred.
  2. Letter which may be 'L'(level), 'D'(degree) or 'G'-'U'(referring to the complementary criteria, 'G'(growth index) or 'U'(unsafeness index)). Thus, it refers to the criteria being represented.
  3. Some letters between brackets which can be the following:
     - MAX → 10 crews with maximal growth or unsafeness (matching with the x-axis) of every season represented in the model.
     - MIN → 10 crews with minimal growth or unsafeness (matching with the x-axis) of every season represented in the model.
  4. 'm' value, which refers to the slope of the the line chart drawn.

     From it will be easy to notice the overall tendency of the results.
  5. Value between brackets which indicates the average of value calculated.
- Over each point forming the line charts, there is a vertical line of the same color (a bit faded), which indicates the SD measure calculated from the point calculation (average of individual results, having degrees of the same discrete cut).
- Moreover, notice the following general characteristics:
  1. Circles, as well as cold colors (blue, green and cyan), always refer to the *growth index* criteria
  2. While triangles and hot colors (red, yellow and magenta) refer to *unsafeness index*
  3. In all plots the legend is identical, though it is only to notice which color corresponds to which information in order to interpret all results, or comparing them.



(a) Results from the crews with growth extreme values.



(b) Results from the crews with unsafeness extreme values.

Figure 6: The above figures illustrate the results from analysing the crews with extreme growth and unsafeness values in each season represented by the model.

In figure 6a it can be appreciated that the overall tendency of the correlation of how the growth of crews which have extreme growth index values, with other criteria. The observations on the results illustrated are the following:

- The *level* of crews has a raising tendency as the growth index increases.
- The *unsafeness* has a raising tendency as the growth index increases.
- Whereas, the *degree* has a dropping tendency.

In figure 6b it can be appreciated that the overall tendency of the correlation of how the growth of crews which have extreme unsafeness index values, with other criteria. The observations on the results illustrated are the following:

- The *level* of crews has a significant decreasing tendency as the unsafeness index increases.
- Whereas, the *growth* it maintains the same independently to the changes on *unsafeness*, moreover, notice that the average growth in both cases is appealingly very similar between them (and equal to zero).
- While, the *degree* has a clear raising tendency.

6. Discussion on the results

In this section the results presented in sections 5.3 and 5.4.1, together with the results illustrated in section C.2 (Appendix C), are discussed and the main conclusions from the results are driven.

Degree distribution analysis

- The model does not fit with any of both compared types of networks:
    1. Random networks
    2. Scale-free networks
- The degree distribution is not well regressed by the methods implemented:
    1. Maximum likelihood estimator
    2. Power-law exponent regression

Correlating interactions between crews to performance evolution

- It was not possible to confirm the initial hypothesis, on which this project was based:
    1. Regarding the *growth* of crews, it does not seam to have a strong dependence on the degree, of any of both type of relations, neither in their joint model.

2. The *unsafeness index* shows an overall increasing tendency when degree increases. Indeed, it contradicts the initial expectations. Which was that having higher grade of influential relations would lead the crews to reduce their unsafeness rates.

– The results had very high SD.

Correlating extreme performances to other attributes

– The *level* of crews has a raising tendency as the growth index increases.

– The *unsafeness* has a raising tendency as the growth index increases.

– Whereas, the *degree* has a dropping tendency as the growth index increases.

– The *level* of crews has a significant decreasing tendency as the unsafeness index increases.

– Whereas, *growth* maintains the same independently to the changes on *unsafeness*, moreover, notice that the average growth in both cases is appealingly very similar between them (and equal to zero).

– While, the *degree* has a clear raising tendency as the unsafeness index increases.

7. Extensions, strengths and weaknesses

This section presents the evaluation conclusions on the performance analysis, of this project.

7.1. Extensions

Due the time limitation resources it was not possible to implement the different alternatives for the temporal model and compare them. Neither to explore further interesting methods for the knowledge extraction process.

Next some other possible extensions are exposed:

- Performing quality analysis on the model design, in order to ensure that the model is robust and that the data is correctly represented.

- Performing quality analysis on the criteria design, in order to ensure that the model is robust and that the data is correctly represented.

- Using the full expressiveness of the data for building a more complete model, adding extensions on the presented approach (e.g. adding a new type of relations named *giving example*, where the best crew is willing to demonstrate their superiority to others, but without any pressure of rivality).

- Adding new criteria, which could be interesting to be added in the analysis process (e.g. *safeness gain*, which could be calculated by comparing the current safeness with the previous seasons one).

- Performing statistical analysis on the results retrieved, in order to determine the robustness on the conclusions, and furthermore, being able to draw strong conclusions from the results analysis.
- Using the knowledge extracted from the analysis implemented, for feeding a real application, such as a human towers crews RS[11].
- Using prediction models for inferring the future of a crew in global terms, instead of just performing temporal smoothing for defining most of criteria.

7.2. Strengths

Complex networks and “Castells” are trendy topics, moreover, when related to modelling real data, which involves having to dig on the available sources, and investigating around, for creating new datasets.

The paper gives a clear and brief insight about the most important elements in the complex networks modelling and analysis design process, focusing on the specific scenario of the human towers crews. While applying the reviewed approaches to a real case, using a new handcrafted dataset.

Other strengths of this project would be:

- The target scenario proposed is in an very interesting stage of its history, which commonly is named the “The platinum period”, referring to the most amazing period until now. Moreover, the topic is related to the local culture, where the project is being carried.
- All the information used and presented in this paper is real information, extracted from a handcrafted historical dataset of the human tower crews performances over the last five years. The problem and the data where not academically designed, but searched and reviewed. Therefore, the problem was solved on the real field and its solution, could be extended as a working application for real users, willing to join a crew.

7.3. Weaknesses

During the development of this project some problems appeared, forcing changing the initial planing, to the finally presented in this paper. The two most relevant issues during this work were:

- The impressive amount of definitions required for giving to the project the robustness and support necessary for presenting it as a serious report, on a real study case using real data.

11. Recommender system

- The lack of previous work regarding the modelling of the human towers crews, at any level. Forcing the complete and exhaustive description and justification of every single step within the process of defining the model as it has been defined, together with all its characteristics, limitations and simplifications. Also, all the evaluations on the parameters had to be designed from scratch.
- The previous two points, leaded to an unavoidable overload of work, which precluded the possibility of programing the multicriteria RS, fed from the knowledge extraction from the dataset, in order to obtain a real working application, which could automatically represent the full set of alternatives (i.e. the existing 71 human towers crews around the world) and recommend the most suitable choice given a specific user profile.
- There did not exists any complete historical record of the human towers crews activity, of easy access. In fact, it was necessary to perform more than one hundred queries to obtain the data composing the used dataset.
- Much information was not even public. Such as crews number of members insured, which would have permitted representing more accurately the *Crew size* criteria (which due to this restriction was finally excluded from the presented model); or cost per year of the insurance per each crew, which would allowed a more precise representation of the severity of falls suffered by crews, thus, building a more robust *Unsafeness index* criteria, by weighting the falls depending on the bill of the hospital (if any).
- Due to the complexity on finding correlations from the degree of the nodes to the other criteria evaluated, it was insensible to focus on performing statistical analysis on the results, in order to presenting strong conclusions in this paper.

8. Concluding Remarks

This paper presents an approach for modelling the *Castells crews* complex network, for solving the problem of finding correlations between the human towers crews interactions to their performance evolution over time. With the aim of extracting new knowledge, and driving interesting conclusions regarding a topic, which was never analysed from this perspective before, in reviewed literature.

The selected design for building the model was a collection of weighted directed graphs, which were fed from new data, together with temporal smoothing from the previous state information.

8.1. Future work

As has been commented in section 7.1, there exist many improvements which could be performed in order to continue this project. However, it would be perhaps more reasonable to test the current design before going further, in order to detect functional weaknesses on the model presented.

It has already been noticed that the *Unsafeness index* regulation, is actually perhaps to strict, although it has a sensible measurement strategy. A better approach to this problem, would be finding an alternative calculation which better reflects the danger index of a certain crew, when compared to the rest, but without retrieving dramatic results, when there was just one insensible register of their activity.

Performing further exploration on the possible interesting properties that could be represented as part of the criteria, using additional information sources, such as social media content (e.g. *friends* opinions of crews, ideologies of users and crews matching, average displacement for playing, usual events where it takes part, such as participation in the *Concurs*ConcursCastells, etc.).

8.2. Conclusions

In order to design properly the complex network temporal model, this paper presents a deep research on the related review on the literature surrounding the *Castells* topic was performed. Thus, after this work a strong understanding about how to search data for designing a complex network model analysis, with all the sub-designs required (i.e. scenario definition, model design, criteria design, analysis design, knowledge extraction strategies, etc.).

This paper presents a practical application case of the complex network modelling techniques, for solving a multicriteria representation problem on real researched data.

Related literature has been reviewed showing that a lot of work is being done with this methods, but still there is a lot to explore.

The research performed regarding the complex networks modelling leaded too some main conclusions:

1. For solving properly a multicriteria problems, a strong description on the domain is required.

2. Although the data exists, not much work has been done within the local topics. In fact, the datasets do not exist by them selves, difficulting the access and usage to data. Which could held to mutual benefits, by creating applications and promoting the local culture.

3. Big-data is leading to changes in the modelling paradigm, since there is too much data to be able to model it traditionally. Which, in any case, would lead to an overfitted model.

4. Several research is being done on the same line of the principles presented by Roy (1968). However, it seams not to be the most popular techniques applied to the RS currently, this area is mainly predominated by ML[12] and MAS research groups.

12. Machine learning.

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Appendix A. Table of Points in 2016

ROW	GROUP	SUBGROUP	HUMAN TOWER	LOADED POINTS	UNLOADED POINTS
1	GROUP 0	sub 1	2 de 6	120	140
2			p de 5	135	155
3	GROUP 1	sub 1	9 de 6	165	190
4			4 de 7	175	200
5			3 de 7	185	210
6	GROUP 2	sub 1	3 de 7 a	240	265
7			4 de 7 a	250	275
8		sub 2	7 de 7	250	290
9			5 de 7	265	305
10		sub 3	7 de 7 a	300	320
11			5 de 7 a	310	330
12			3 de 7 s	315	335
13	GROUP 3	sub 1	9 de 7	365	420
14			2 de 7	385	440
15			4 de 8	400	460
16		sub 2	P de 6	425	485
17			3 de 8	445	510
18	GROUP 4	sub 1	7 de 8	550	635
19			2 de 8 f	580	665
20			P de 7 f	610	695
21		sub 2	5 de 8	640	735
22			4 de 8 a	700	770
23			3 de 8 a	730	805
24			7 de 8 a	740	815
25		sub 3	5 de 8 a	765	845
26	GROUP 5	sub 1	4 de 9 f	920	1055
27			3 de 9 f	965	1110
28	GROUP 6	sub 1	9 de 8	1210	1390
29		sub 2	3 de 8 s	1325	1460
30			2 de 9 fm	1330	1530
31			P de 8 fm	1395	1605
32		sub 3	7 de 9 f	1465	1685
33			5 de 9 f	1515	1740
34			4 de 9 fa	1630	1800
35			3 de 9 fa	1680	1855
36		sub 4	5 de 9 fa	1765	1945
37	GROUP 7	sub 1	4 de 9 sf	2015	2315
38			2 de 8 sf	2080	2395
39			3 de 10 fm	2130	2450
40			9 de 9 f	2130	2450
41			4 de 10 fm	2215	2550
42		sub 2	2 de 9 sm	2330	2675
43		sub 3	P de 9 fmp	2445	2810
44			3 de 9 sf	2565	2950

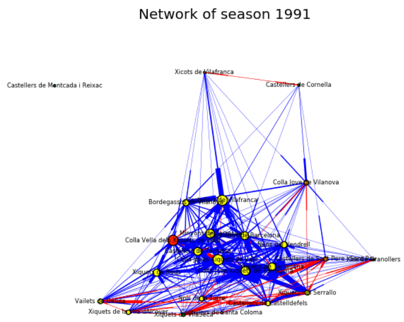
Table 2: Points table for the 26th edition of the "Concurs de Castells"(PointsTable).

Table 2 shows the official evaluation metrics for the human towers decided for the 2016 "Concurs", which will be the evaluation metrics used during this project.

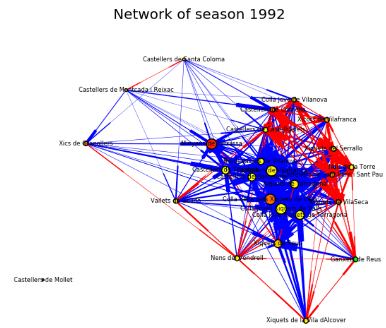
Appendix B. The model complete visualisation

In this section the overall model is reviewed, which as already has been stated, is composed by one network for each season evaluated.

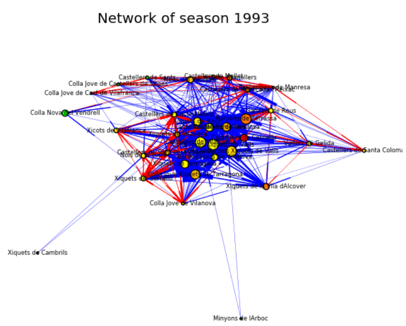
For properly interpreting the following figures information, see the description of the model's representation in section 4.7.



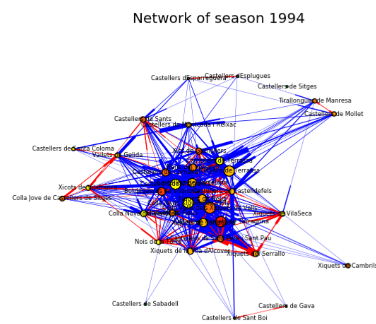
(a) Season 1991.



(b) Season 1992.

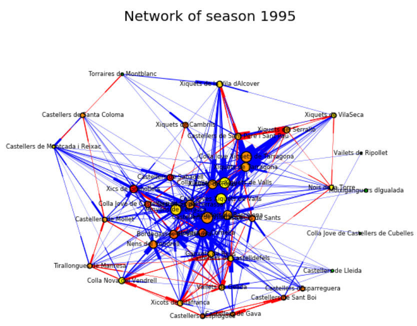


(c) Season 1993.

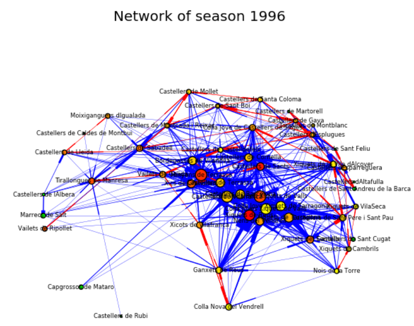


(d) Season 1994.

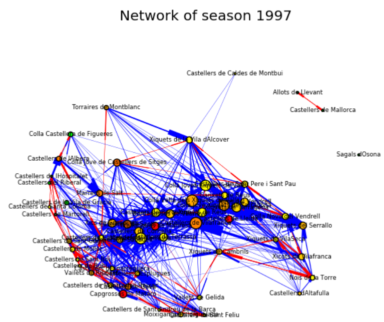
Figure 7: The above figures illustrate the submodels representing season from 1991 to 1994.



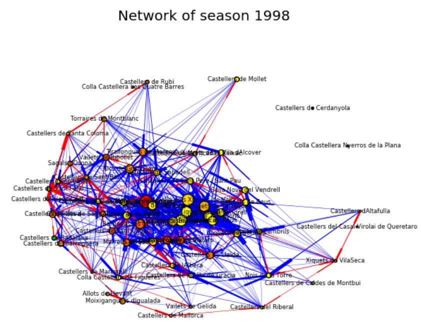
(a) Season 1995.



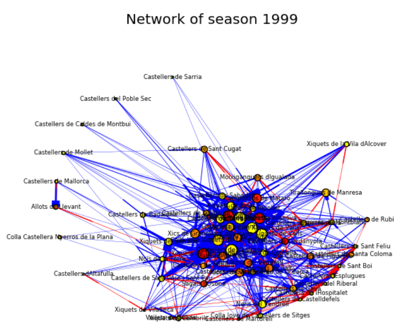
(b) Season 1996.



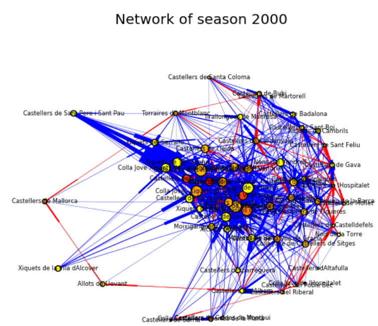
(c) Season 1997.



(d) Season 1998.

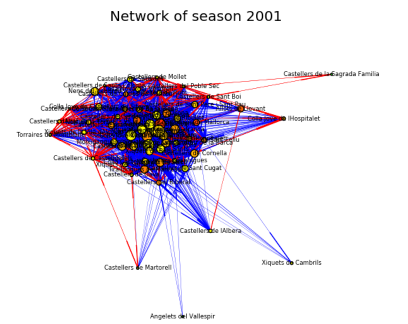


(e) Season 1999.

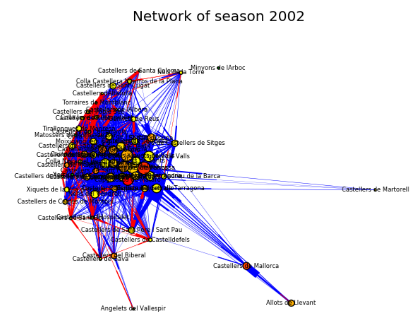


(f) Season 2000.

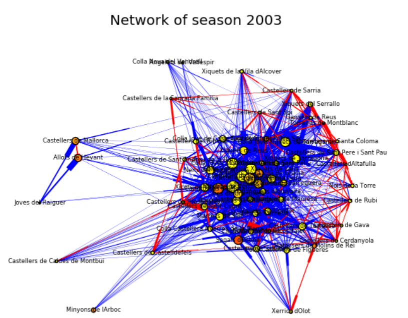
Figure 8: The above figures illustrate the submodels representing season from 1995 to 2000.



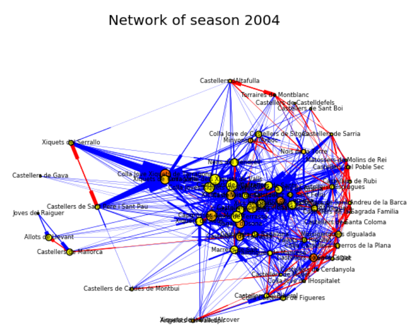
(a) Season 2001.



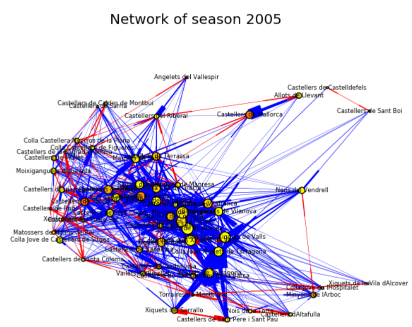
(b) Season 2002.



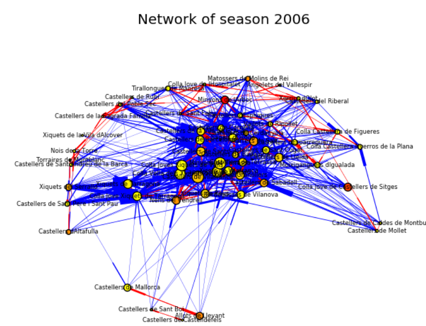
(c) Season 2003.



(d) Season 2004.

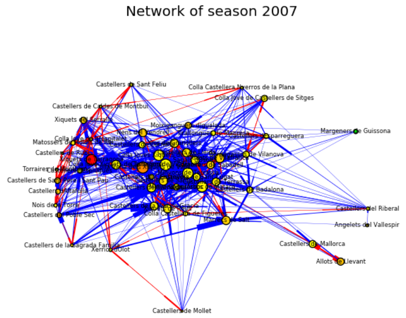


(e) Season 2005.

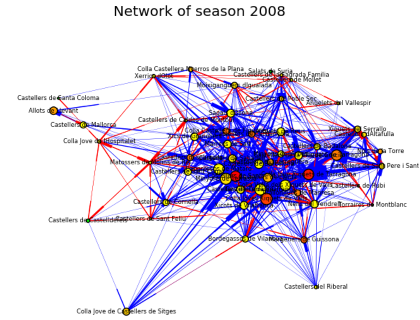


(f) Season 2006.

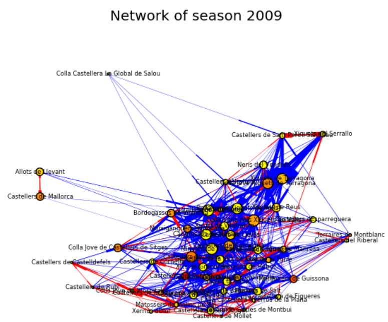
Figure 9: The above figures illustrate the submodels representing season from 2001 to 2006.



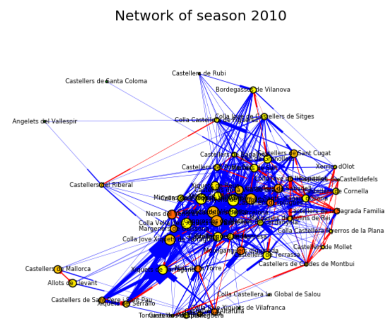
(a) Season 2007.



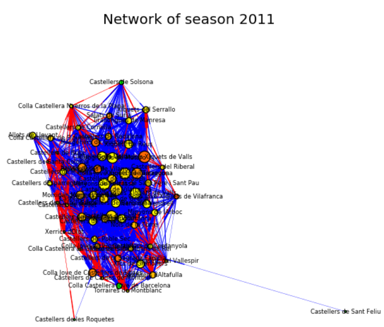
(b) Season 2008.



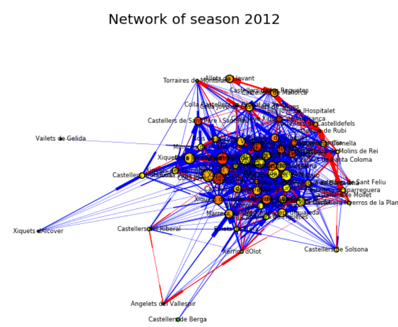
(c) Season 2009.



(d) Season 2010.

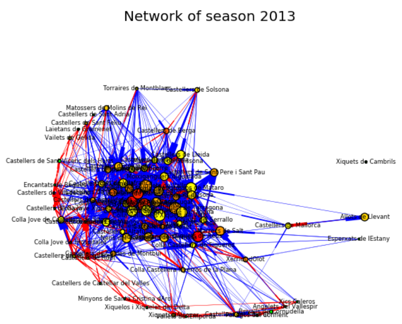


(e) Season 2011.

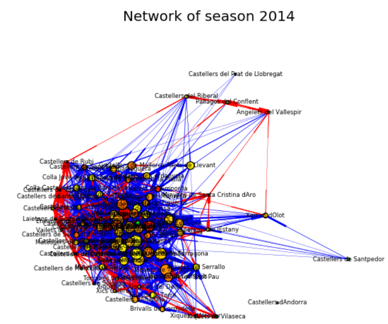


(f) Season 2012.

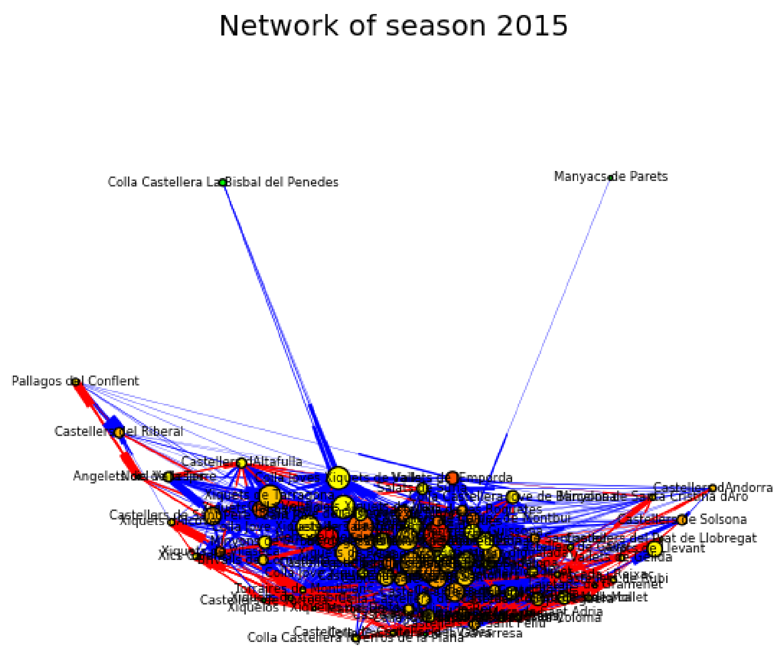
Figure 10: The above figures illustrate the submodels representing season from 2007 to 2012.



(a) Season 2013.



(b) Season 2014.



(c) Season 2015.

Figure 11: The above figures illustrate the submodels representing season from 2013 to 2015.

Appendix C. Additional results from the analysis

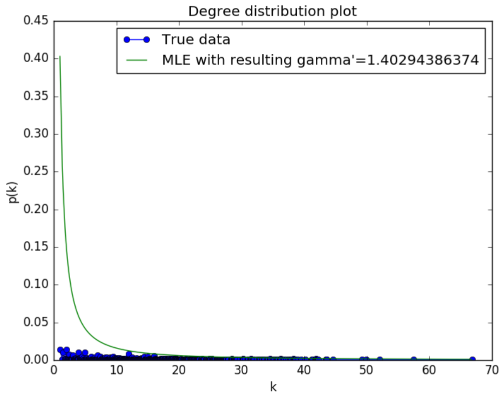
The aim of this section is providing the partial results retrieved during the analysis methods applied to the model presented in this paper, in order to support the conclusions on the results exposed in this paper.

Thus, this section includes additional information retrieved from the experiments, which was used internally for designing the final analysis presented in section 5.2, and also the complete results retrieved during the main analysis strategies implemented, which are used for driving the discussion on the results drawn in section 6.

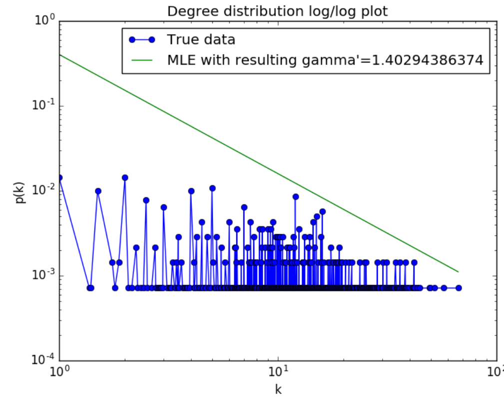
C.1. Pre-analysis results: Degree analysis

This section presents the results commented in 5.1.1.

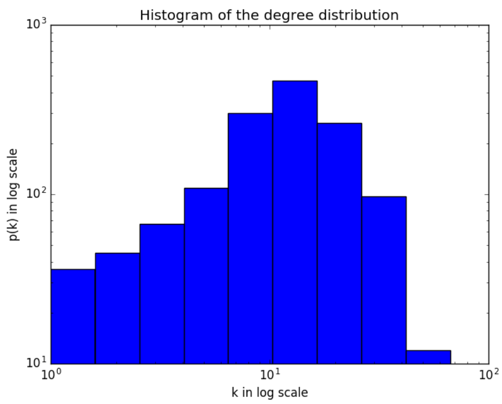
The following figures illustrate the results retrieved from the pre-analysis strategy implemented, the weighted edges degree distribution analysis.



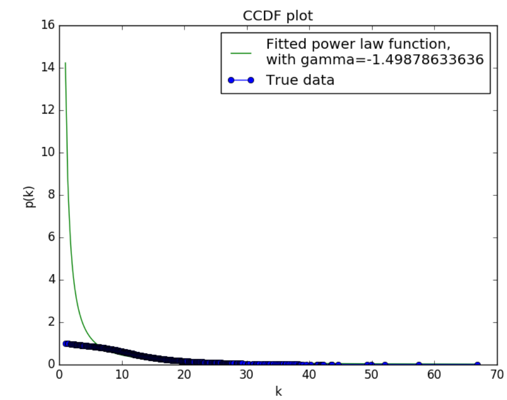
(a) Degree distribution plot.



(b) Degree distribution plot in *log-log* scale.

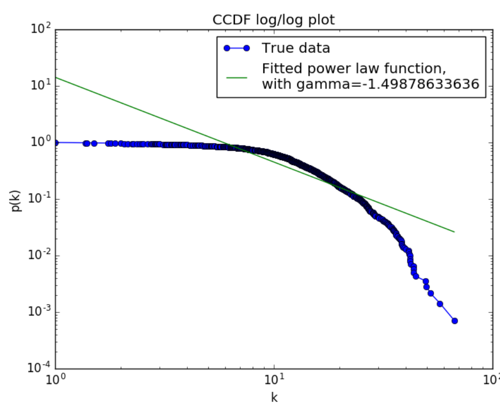


(c) Degree distribution histogram plot in *log-log* scale.



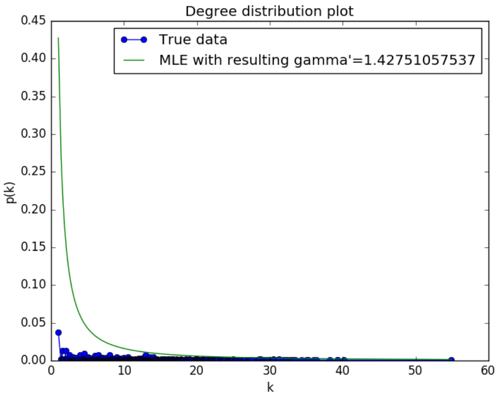
(d) CCDF[a] plot.

a. complementary cumulative degree distribution

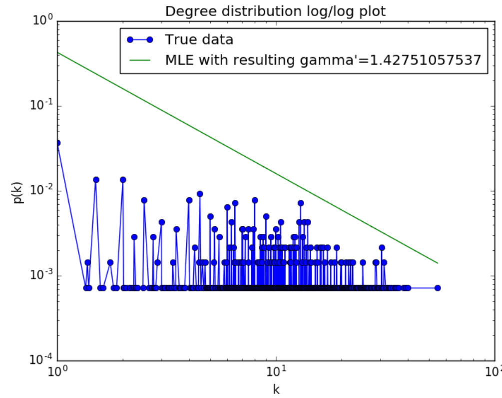


(e) CCDF plot in *log-log* scale.

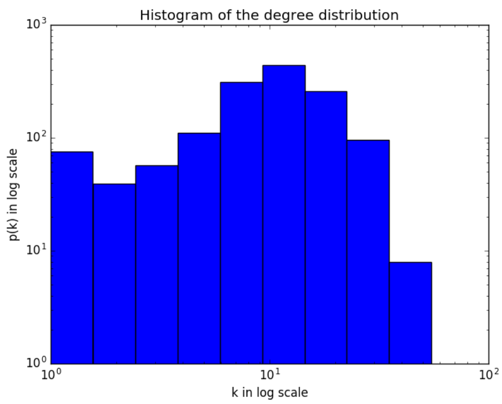
Figure 12: Overall model with all the relations, which has the following results: MLE $= 1.403$, power-law $\gamma = -1.499$, regressed value of $C = 1.15327$.



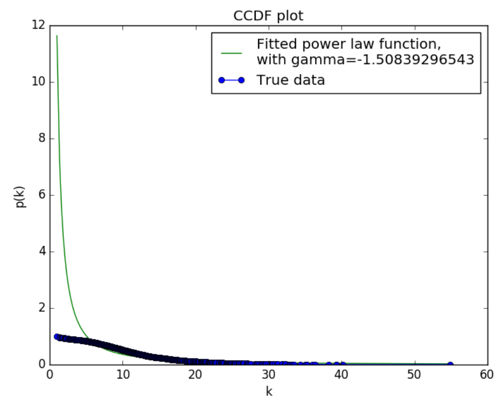
(a) Degree distribution plot.



(b) Degree distribution plot in *log-log* scale.

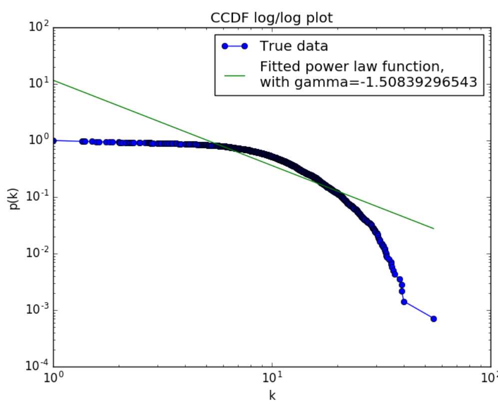


(c) Degree distribution histogram plot in *log-log* scale.



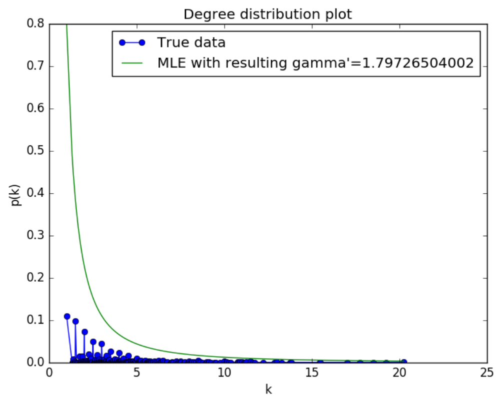
(d) CCDF[a] plot.

a. complementary cumulative degree distribution

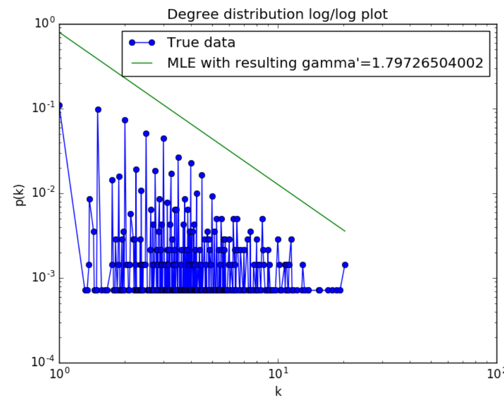


(e) CCDF plot in *log-log* scale.

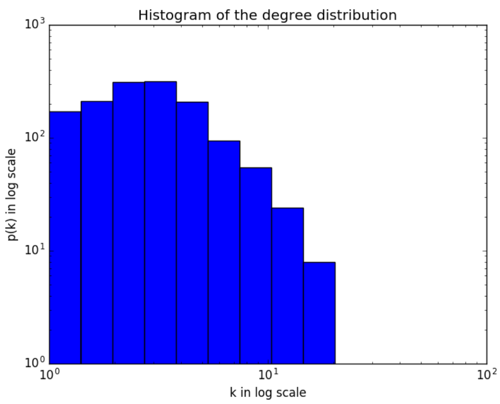
Figure 13: Overall model with only the *know how* relations, which has the following results: MLE = 1.428, power-law $\gamma = -1.5084$, regressed value of $C = 1.0657$.



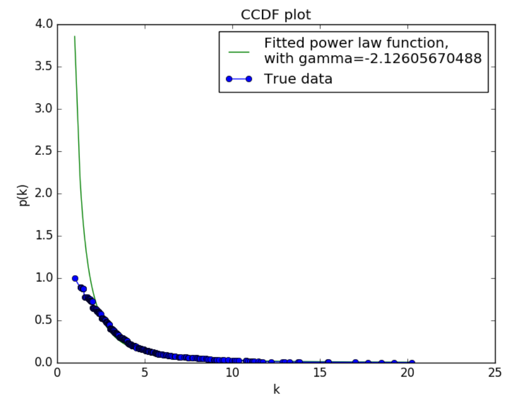
(a) Degree distribution plot.



(b) Degree distribution plot in *log-log* scale.

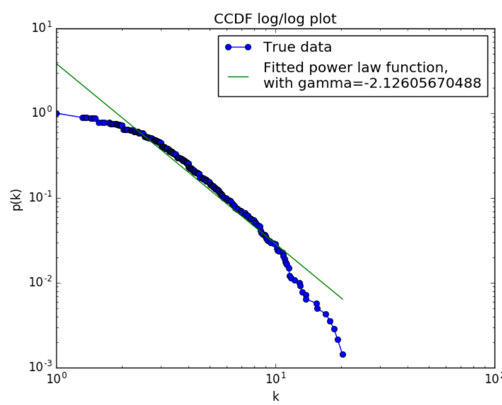


(c) Degree distribution histogram plot in *log-log* scale.



(d) CCDF[a] plot.

a. complementary cumulative degree distribution



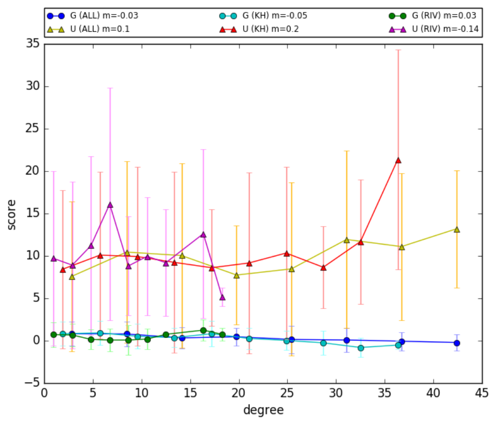
(e) CCDF plot in *log-log* scale.

Figure 14: Overall model with only the *rivality* relations, which has the following results: MLE = 1.797, power-law $\gamma = -2.126$, regressed value of $C = 0.586$.

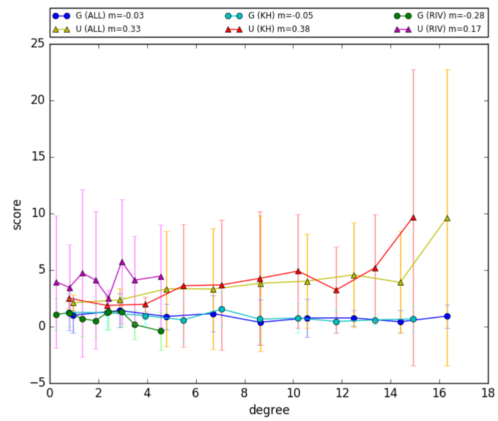
From the presented figures it can be observed that the degree distributions shown do not follow any of the expected generic distributions (power-law, Gaussian or Poisson distributions).

C.2. Additional analysis results: Less representative parts

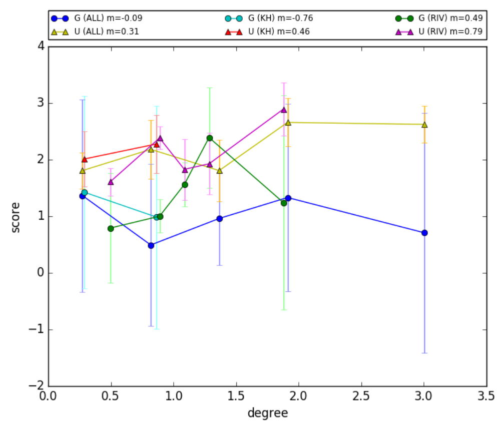
This section presents the results skipped in 5.3.2.



(a) Results from *small* crews.



(b) Results from *medium* crews.

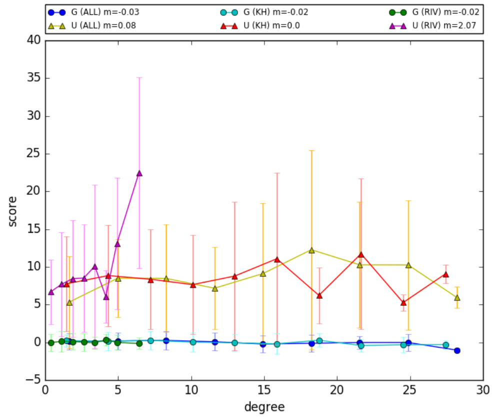


(c) Results from *large* crews.

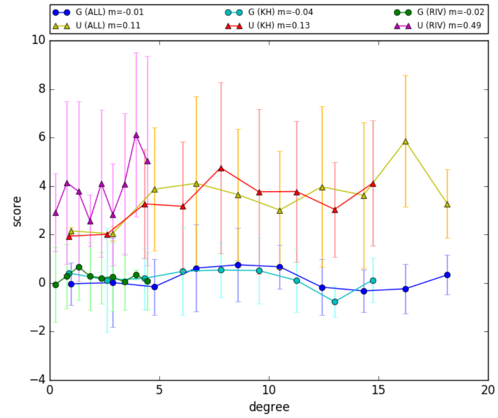
Figure 15: The above figures illustrate the results from analysing the *first raise* period, with different subsets of crews.

In figure 15 it can be seen that the plots reassemble much to the overall models, this is due the fact that due to the significant growth experimented by the human towers crews within this period, thus, the data gathered from it composes a significant part of the global overall data recorded. *Notice that this period of time is also commonly named as the renascence period. Which refers to the fact that Castells recover part of their past glory.*

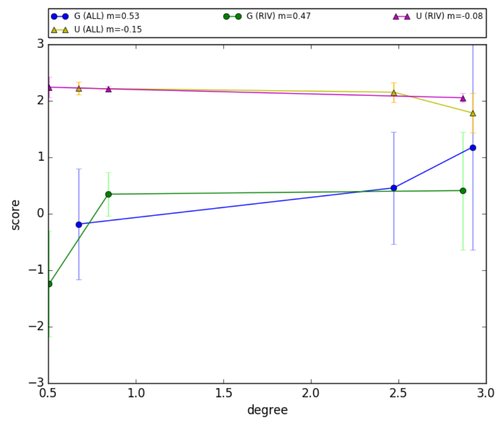
In figure 16 it can be seen that the the figures are quite “weak”, in fact only the small and medium crews figures are significant. Since the figure representing the large crews is



(a) Results from *small* crews.



(b) Results from *medium* crews.

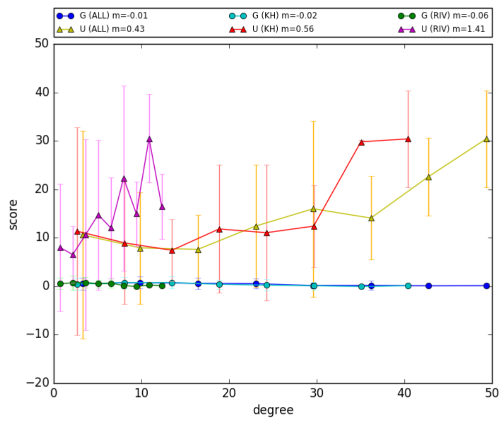


(c) Results from *large* crews.

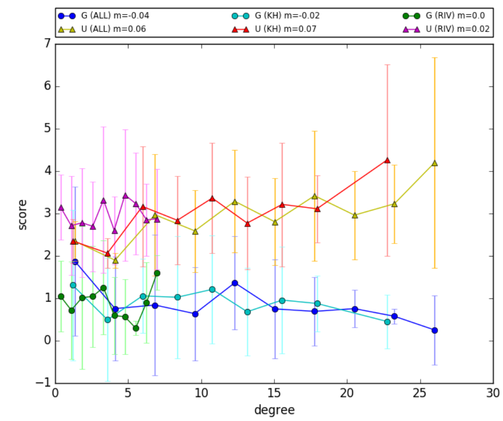
Figure 16: The above figures illustrate the results from analysing the *depression* period, with different subsets of crews.

almost empty. This characteristics were expected, since the *depression* period has this name due to an overall decrease of all performance criteria regarding the *Castellers* crews, not only in participation of people, but low performance levels of crews, as can be observed.

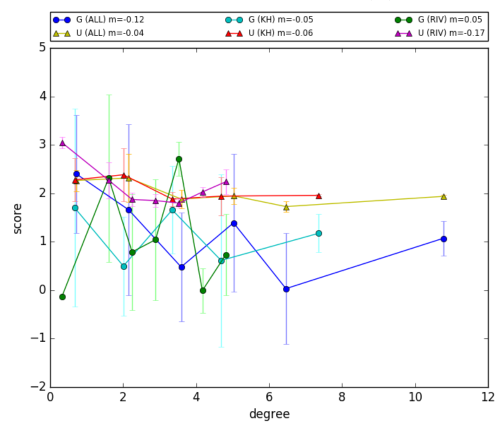
In figure 17 it can be seen that the plots reassemble much to the overall models, this is due the fact that due to the enormous growth experimented by the human towers crews within this period, the data gathered from it composes a very significant part of the global overall data recorded.



(a) Results from *small* crews.



(b) Results from *medium* crews.



(c) Results from *large* crews.

Figure 17: The above figures illustrate the results from analysing the *depression* period, with different subsets of crews.