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Weather-wise: A weather-aware planning tool for improving construction productivity and dealing with claims

Authors:

Ballesteros-Pérez, Pablo [a] ; Rojas-Céspedes, Yonatan Alexis [b] ; Hughes, Will [c] ;
Kabiri, Shabnam [d] ; Pellicer, Eugenio [e] ; Mora-Melià, Daniel. [f]; del Campo-Hitschfeld, Maria Luisa [g]

[a] Lecturer
School of Construction Management and Engineering
Whiteknights, Reading RG6 6AW
United Kingdom
Email: .ballesteros@reading.ac.; @hotmail.com
Phone: +44 (0) 118 378 7186 Fax: +44 (0) 118 931 3856
Corresponding author

[b] Construction engineer
Facultad de Ingeniería. Universidad de Talca
Camino los Niches, km 1. Curicó (Chile)
Tel.: (+56) 984 330 846
Email: .y@gmail.com

[c] Professor
School of Construction Management and Engineering
Whiteknights, Reading RG6 6AW
United Kingdom
Phone: +44 (0) 118 378 7175 Fax: +44 (0) 118 931 3856
E-mail: w.p.hughes@reading.ac.uk

[d] Lecturer
School of Construction Management and Engineering
Whiteknights, Reading RG6 6AW
United Kingdom
Phone: +44 (0) 118 378 6038 Fax: +44 (0) 118 931 3856
E-mail: s.kabiri@reading.ac.uk

[e] Associate Professor
Civil Engineer, M.Sc., Ph.D.
School of Civil Engineering. Universitat Politècnica de València
Camino de Vera s/n, 46022, Valencia, Spain
Phone: +34 963 879 562 Fax: +34 963 877 569
E-mail: pellicer@upv.es

[f] Assistant Professor
Dpto. de Ingeniería y Gestión de la Construcción
Facultad de Ingeniería. Universidad de Talca
Camino los Niches, km 1. Curicó (Chile)
Phone.: (+56) 75 2201786 Fax: (+56) 75 325958
E-mail: @utalca.

[g] Assistant Professor
Centro de Sistemas de Ingeniería KIPUS
Facultad de Ingeniería. Universidad de Talca
Camino los Niches, km 1. Curicó (Chile)
Phone.: (+56) 75 2201767 Fax: (+56) 75 325958
E-mail: @utalca.; @kipus.

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Abstract

The influence of unforeseen, extreme weather in construction works usually impacts productivity, causes significant project delays and constitutes a frequent source of contractor's claims. However, construction practitioners cannot count on sound methods for mediating when weather-related claims arise, nor harnessing the influence of weather variability in construction projects. Building on the few most recent quantitative studies identifying those key weather agents and levels of intensity that affect some standard building construction activities, a new stochastic model that processes and replicates the spatio-temporal variability of combined weather variables is proposed. This model can help anticipate weather-related project duration variability; improving construction productivity by selecting the best project start date; and objectively evaluating weather-related claims. A two-building construction case study using different Spanish locations is used to demonstrate the model. This show that ignoring the influence of weather can lead to project durations of 5-20% longer than planned.

Keywords: *Building; Productivity; Weather; Climate; Claims; Delays.*

1. Introduction

Construction projects consist of numerous technological operations that can generally be structured in multiple alternative ways. The work breakdown structure (WBS) and the activity precedence relationships have a big impact on the actual project duration. However, the sensitivity of technological operations to adverse (local) weather conditions is also frequently recognised as one of the factors causing noticeable project delays, cost overruns, and contractual claims [1].

According to Mentis [2], projects may take significantly longer, cost more and foster a larger number of conflicts partly when threat identification is inaccurate, its scope is too narrow or its assessment is not satisfactorily incorporated into the project contract, planning and execution stages. Overall, the lesson from Mentis, involving construction projects from several developing countries, is that “almost by definition, what is poorly known is likely to cause problems”. Maybe not that surprisingly though, adverse weather conditions stand out as one of the most recurrent threats in half of the projects discussed in his analysis.

The presence of unfavourable and unpredicted weather conditions can only have two possible outcomes from the execution point of view. The first is work that is suspended until the adverse weather subsides (prolongation). The second is the need to apply extra costly measures to counteract the influence of the weather and continue carrying out the works (disruption). Either outcome irremediably leads to extra time, the need for more resources (lower productivity) and, eventually, financial losses. Any of these consequences may cause disputes among the contractor and the client because, eventually, someone has to pay.

Accordingly, the influence of weather in construction projects is recognised by both researchers [3–5] and practitioners [6,7] but with two very different interests and motivations. Researchers are mostly focused on work that systematically addresses the influence of poor weather conditions in planning project execution or modelling building performance (e.g. [4,8–12]). Practitioners mostly focus on issuing recommendations for preparing weather-proof construction systems [7] or drawing up contracts that can deal with weather-related and delay-related claims [6,13]. In both cases, despite the different aims of each group, it is clear that regular practice has subdivided the weather into two categories: foreseeable and unforeseeable.

Foreseeable, or just “normal” weather can be relatively easily inferred from historical weather data [5], which is typically processed as a monthly average of severe weather days. This can be used to anticipate the average number of days in which a specific construction activity cannot be carried out [14].

Ideally, the effects of normal weather on construction works should be routinely taken into account. Ballesteros-Pérez *et al.* [15] have shown that, unfortunately, and despite its inherent simplicity, few projects take account of the weather factor systematically in the planning and execution stages. There are two reasons for this: compressed tender periods and availability of data for a specific site. Tender periods are frequently too short, as discussed by Hughes *et al.* [16]. Moreover, a lot of information needed for preparing a bid is simply missing at that stage. Thus, estimating and planning may be far less reliable and organized than it should be. This can be exacerbated by the, sometimes, large differences between the weather on a specific site and the weather at the nearest meteorological station. However, even if normal weather data were regularly used, three problems arise. First, the weather involves the confluence of multiple phenomena (wind, rain, heat, etc.) and those phenomena, contrary to expectations, do not involve a clear correlation of occurrence with each other. This will be proven later in this paper. Second, each weather agent has variability, and that variability has been addressed by very few studies [4], generally combining only up to two or three phenomena (see Table 1). Third, weather data are generally measured at a ground level, probably quite far away from where the construction works will be located [14], and, perhaps, with a different topography [17].

Concerning unforeseeable or abnormal weather, it is, paradoxically, brought up more frequently in the daily practice of projects, as most construction contracts usually include clauses stating that the contractor may be entitled to a time extension or cost compensation due to the occurrence of unusual severe weather conditions [18–20]. Yet, the problem is that normal weather conditions, or rather their interaction in relation to productivity decrease, are not properly known or registered somewhere (e.g. in the contract itself). Hence, how is it possible to compare a severe weather episode or its effects versus an inexistent baseline? In other words, how is it possible to state that something is abnormal when normal weather is neglected by default?

The aim of this study is to tackle preconceptions about weather-related uncertainty. This will be achieved by developing a holistic model that enables practitioners to use weather data for forecasting project durations, improving construction productivity and the settlement of contract claims. A case study is carried out involving the construction of two different buildings in different Spanish locations. This enables several applications of this model to be developed for progressively dealing with three aspects: normal weather, its multivariate statistical variability, and distinguishing exceptional from non-exceptional weather. Such applications allow the reduction of weather-related uncertainty at the planning and construction stages. They also provide an objective and independent estimate as to how exceptional the weather conditions were at the construction stage. Hence, in general, the model will allow working ‘weather-wise’, that is, in favour of the weather, instead of against it.

2. Literature review

2.1 Weather and claims

The risks of weather-related delays are generally dealt with in contracts through provisions such as weather, default, and *force majeure* clauses [19]. However, from the standpoint of the contractor, the effect of weather in construction works is materialised in two ways: work stoppage or productivity loss [14]. Severe weather conditions impact any construction work that is either totally or partially carried out outdoors because either the equipment cannot work properly, the quality of the materials is deteriorated, or workers' health and safety is threatened [21]. Regardless of the reason, the consequence is a financial loss that must be borne by either the contractor, the client or both.

From the client's perspective, the initial effects of weather issues are mostly connected to project (time) delays [19,22]. Only if the contractor tries to mitigate weather-related losses at the expense of the client, or if due to an inauguration delay the client misses a business opportunity (e.g., the timely exploitation of an infrastructure), will the extreme weather also entail financial losses for the client [23]. Unfortunately, the weather impact is almost always associated with negative effects for these two key stakeholders. It is no surprise that many regulations and codes of practice have tried to address the effect of weather on construction works but , so far, with not much success [15].

The common problem with most contracts is that they are qualitative, too generic and/or not conveniently updated (e.g. [24–30]). Yet contractors need to know how the weather will impact their construction work, and both the contractor and the client require "clear and specific" weather-related clauses in the construction contract in order to mediate between their interests. The challenges to reach these objectives are manifold. First, it is necessary to objectively identify which weather variables are relevant. Second, which are the intensities (threshold values) beyond which some construction activities will be affected and even to what extent they might be affected. Third, which party/parties are to assume the consequences (financial losses) if a severe weather episode happens. The first two challenges have not yet been solved by the research community [19]. The third challenge, which is the one reflected in contracts and connected to practitioners' interests, remains loose and unclear [31]. Overall, the three have become a recurrent source of conflict [32,33].

An alternative approach to dealing with these issues is to exclude any clause that deals with weather-related delays. In such cases, there are no excusable delays relating to weather. This would mean that all weather-related delays are treated just as a consequence of the contractor's mismanagement, lack of foresight or irregular work processes [19]. The downside of this approach is that the consequences are always absorbed by one side, the contractor, and since this party also has leverage in other contract aspects [3], in the persistent absence of shared responsibilities, legal claims and disputes are likely to arise and escalate [34].

2.2 Weather and productivity

Extremely adverse weather conditions are frequently identified as one of the top causes producing project delays and waste of resources (e.g. [2,3,32,33,35]). As can be easily deduced, a project delay is the result of a temporary work stoppage or a performance decline at some point; both of which could be labelled as lower-than-expected productivity.

The real problem becomes more evident when one tries to establish a quantitative relationship between specific weather variables, their levels of intensity and their corresponding impacts on productivity. As stated earlier, this is the real source of conflict because the same level of intensity (for example 10 mm of precipitation or high/low temperatures) can cause very different effects depending on several aspects such as the nature of the project, contractor’s equipment, soil materials, geotechnical conditions, landscape topography, intensities of other concomitant weather agents, even the country in which the project is being built. Indeed, construction workers exhibit very different temperature tolerance depending on their country of origin. In addition, it is important to consider the contractor’s anticipation of the weather and whether any specific approaches were implemented beforehand to mitigate the impact of the weather.

Due to the wide range of factors when trying to establish measurable relationships between intensities and consequences of weather agents, very few quantitative research studies have addressed these specific shortcomings. In this regard, Table 1 identifies and summarises the most significant “quantitative” works by including their scope (nature of works), the construction activities discussed, and the specific weather agents that were analysed.

<Insert Table 1 here>

As shown in Table 1, although the weather factor is recognised as having a significant influence on construction work, quantitative studies connecting the intensities of weather agents with construction activities are rather scarce and, mostly, less than ten years old. To sum it up, the situation is that quantitative research has merely scratched the surface of the tripartite weather-productivity-delay issue [35]. Most national regulations and contracts are too vague or just not quantitative enough to allow their application. Yet, the weather problem in construction projects is a real and pressing matter due to its high-frequency and severe financial implications.

3. Materials and methods

3.1. Methodology outline

In the next subsections a model is developed. The purpose is to enable weather data to be used for forecasting project durations, improve construction productivity, and settle contract claims.

First, the kind of weather that impacts some standard and typical construction operations is identified. Identifying the corresponding intensities of relevant weather variables and analysing the historical weather information makes it possible to define the likelihood of performing those standard construction operations. This probability is expressed as a proportion of workable days per month and labelled climatic reduction coefficients (CRCs).

Second, the spatial and seasonal variation of the CRCs are analysed in the peninsular region of Spain for certain typical construction operations: earthworks, formworks, concrete, steelworks, scaffolding, outdoor paintings, and asphalt pavements.

Third, the kind of weather analysis that is usually performed, with an average (deterministic) approach, is revisited. However, this time with a stochastic approach. This stochastic treatment of the weather allows the calculation of a probability distribution curve for any construction project duration. It also enables the determination of, among other things, the optimum start date so that the overall project duration is minimised.

Fourth, a case study involving the construction of two buildings in different cities of Spain is developed. This case exemplifies how the decision about where and when a project is carried out entails significant financial implications.

Fifth, it is argued that a slightly adjusted model may be used retrospectively as a tool for mediating in weather-related disputes between the contractor and the project owner.

3.2. Measuring the weather-related productivity impact

Previous quantitative studies have measured some of the impacts of weather variables and intensities on the execution of specific construction activities. As there are several different studies, some simplifications are necessary. This is mainly related to merging and homogenising expressions and thresholds from those studies in Table 1 to enable modelling productivity impacts on some significant construction activities, as shown in Table 2.

<Insert Table 2 here>

Overall, Table 2 is divided in two major vertical blocks: raw climatic coefficients (RCC)[1] and construction activities. The first column of the RCC block (named "Monthly days without…") contains the main weather variables, along with the most commonly agreed thresholds or levels of intensity from the literature. The second column ("Mathematical expressions") shows the way that each weather variable has been translated into a coefficient C_x^i that reflects the proportion of "workable days" in a scale from 0 to 1. The superscript $i= 1, 2, 3 \ldots 12$ denotes the month of the year, whereas the subscript $x = t, p1, p10, p30, w, s, e$ denotes the specific weather variable and/or its intensity. Equations (1) to (7) specify how the seven most relevant C_x^i RCCs are calculated for each month of the year and for a particular location where there is at least one nearby meteorological station.

However, as expected, not all of the weather variables (now converted into RCCs) affect all of the construction activities. In this regard, only the cells populated with references from the last seven columns to the right make explicit the connection between specific RCCs and their impact on each of the construction activities (*E, F, C, T, S, O* and *P*). Most of these references are taken from studies previously reflected in Table 1, along with a sample of construction regulations from three

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[1] We are following Ballesteros-Pérez *et al.*'s [15] notation. According to those authors, naming coefficients as "Climatic" instead of as "Weather" is pertinent since the calculated coefficients are representative of a broader area and approximately stable during a particular period of the year.

countries included as representative examples in Table 2. In the absence of a single intensity agreement among cited sources, either average values were adopted (e.g., the wind speed at 55 Km/h) or several steps of intensities considered (e.g., the precipitation with intensities of 1, 10 and 30 mm).

By establishing the connection of the RCCs to some standard construction activities, the CRCs from the row at the bottom of the table is straightforward. Equations 8 to 14 demonstrate how a composite productivity coefficient, calculated as the product of two to four RCCs, represents the proportion of workable days (on a 0-to-1 scale) in month *i* for each of the seven construction activities considered: earthworks, formworks, concrete, steelworks, scaffolding, outdoor paintings and asphalt pavements (, , , , , and , respectively).

Two major simplifications are assumed. First, only weather influence on technological operations have been considered; that is, no influence on workers' labour productivity (mostly due to high temperature and humidity levels [49]) is included in the analysis. For example, a temperature of 24ºC is considered very high in northern (colder) countries, whereas it is considered optimal in southern (warmer) countries. Therefore, more research is needed to adapt or calibrate this dimension. This is beyond the scope of the present study. Second, although the generic mathematical expression of CRCs in equations 8 to 14 seem quite intuitive (the simple product of RCCs), it is worth checking whether a high covariance between the variables from a RCC might affect (or exaggerate) the CRC values. In this regard, Table 3 reflects the auxiliary calculations of covariances among the seven RCCs from Table 2 in four locations of Spain with different climatic conditions (Valencia, Zaragoza, Madrid and La Coruña). The four covariance matrices indicate how the covariances (values outside the diagonals) are very small in general. This agrees with previous studies and other models which neglect this same effect [50] and makes our second simplification perfectly tenable.

<Insert Table 3 here>

3.3. Monthly and annual average Climatic Reduction Coefficient (CRC) values

So far, very simple calculations have been developed in order to identify the "average" or "normal" weather conditions that might affect some typical construction works. The way they can be implemented in practice simply consists of calculating the RCC values (equations 1 to 7) from the most recent years and then take their respective averages to calculate each of the CRC values (with equations 8 to 14).

As an example, Figures 1 and 2 represent the average monthly and annual data for two of the seven CRC values. These Figures present data from all the peninsular province capital cities in Spain with at least one weather station. The complete set of six CRCs used for the two-building building case study can be accessed as supplemental online material. In these calculations, the average values of the RCC made use of the last 30 years of weather data from the peninsular Spanish weather stations.

<Insert Figure 1 here>

<Insert Figure 2 here>

A first reading of Figure 1 immediately provides some interesting patterns. Earthworks activities are not sensitive to the average Spanish weather since most of the CRC values (which denote the proportion of workable days per month/year) are close to 1 (cells mostly green). The opposite could be said about Outdoor Painting activities in Figure 2; the predominant orange and even red colours highlight much lower values.

As might be expected, summer months (June to September) generally have the highest CRC values, but the location effect is much more important. Cities like Córdoba and Jaén (Andalusia) allow very good working conditions, on average and throughout the year; whereas other cities have the opposite, such as San Sebastián (Basque Country).

One of the limitations of Figures 1 and 2 is that they must be developed for single specific map locations. Arguably, many buildings or infrastructures will, probably, be built within a close radius of one of these urban centres, but there will always be others significantly far from them. Therefore, a spatial extrapolation is necessary to obtain the CRC values where no weather stations are close or data is unavailable. This is exactly what Figure 3 shows for the annual CRC values of the same two CRC coefficients represented in Figures 1 and 2. Again, the complete set of annual maps (*E, F, C, T, S, P*) can be found as supplemental online material. By observing the maps represented in Figure 3, it is easy to see how cities that were mentioned above (Córdoba, Jaén and San Sebastián) are located in areas where the climatic conditions are very favourable or unfavourable, respectively.

<Insert Figure 3 here>

Again, these maps have some obvious limitations. The first is that, as can be anticipated, one map is needed per construction activity and per month. Figure 3 has only represented the annual average of the monthly maps but, obviously, as more activities are considered, more maps would be needed. Although elaboration of these maps can be made with software like Surfer® or ArcGIS®, a multi-layer digital map representation would be preferred over working with multiple paper-printed maps.

The second limitation is that no topography conditions (like the altitude) have been considered, since this would have required the application of more complex algorithms for adjusting the spatial variation of the CRC values. Fortunately, in countries such Spain where the number of weather stations is abundant and very well dispersed all over the country, the massive number of data points means that this analytical simplification is not that crucial. However, it is recognised that, for special projects like high-rise buildings [14] or those with isolated locations and difficult access, these maps would not provide reliable values and the only option would be to resort to more precise on-site weather station measurements (set up preferably at least a couple of years before commencing the project). Many observers may object to the expense of monitoring the weather for two years prior to construction, but the expense is dwarfed by the expense of delayed completion, litigation or other losses following from inadequate data.

3.4. Modelling stochastic weather variability

The understanding brought about by considering weather date, CRCs and RCCs is useful in considering the impact of adverse weather on construction activities. It is clear from the foregoing that weather affects various tasks in different ways. One important factor is that not all kinds of weather occur simultaneously. When one or two variables become abnormally high, progress will be affected. This will cause a real productivity loss and a potential element of dispute between the contractor and the project client. The question is whether weather events with a positive effect might compensate those with negative effects. Current analytical approaches would not help either the contractor or the client to answer such a question. But, based on the approach provided in this study, an objective answer could be provided. More specifically, if all the RCCs are treated as stochastic variables, instead of average values, the overall effect of the weather conditions during the construction phase could be determined.

Many recent studies have addressed multiple ways of generating stochastic weather data for use in operations research and management science [50]. However, applications within the construction environment count among the most numerous [14,37,51]. These provide a basis for extending the analytical model proposed so far.

Generating stochastic weather values is quite simple whenever the covariance among different weather variables is not considered (a simplification that was shown in Table 3 to be tenable in this case study). Basically, previous calculations required that the RCC values are calculated for each month and year of the historical weather data before taking their average. But, if RCC standard deviation values are also calculated along with their averages (mean values) for the *N* years of analysis, fitting a Beta distribution to the monthly RCC values of each weather variable would be straightforward using the method of moments.

As supplemental online material, the third set of figures shows these calculations for the same four cities (by columns) that were selected as examples in Table 3 when calculating the covariance matrices. The RCC values of the 30 years have not been included for the sake of brevity, but indication of the number of values years (*N*), the mean and standard deviation of the *N* RCC values, as well as the α and β shape parameter values for the Beta distributions, representing the monthly RCC values variability, have been stated for each of the seven RCCs. The last row from each of the Tables from the seven RCCs reflects the Kolmogorov-Smirnov *D* statistic which corresponds to the maximum deviation observed between the actual data and the Beta distributions fitted to each month of the year per RCC series of *N* values. From the tables at the bottom, it is easy to check that these *D* values are “without exception” below the critical K-S’s values for three levels of significance (α=1%, 5% and 10%).

Having verified that the Beta distribution has a good fit with historical RCC values, the next step is to use this distribution for generating stochastic values by Monte Carlo simulations, while modelling the climatic trends from previous years. Essentially, once the Beta α and β parameters are calculated for each month and for each type of RCC, one iteration (one artificial year) will produce a series of twelve CRC values. With these values known, it will be possible to calculate the monthly , , , , , and values of that artificial year by just applying equations 8 to 14. Now, it only remains to apply several thousand of these stochastic values to a particular schedule to measure the potential productivity losses and project delays as a consequence of the changing weather.

3.5. Case study: construction of two buildings

To explain the issues more fully, a case study applying the method developed so far is presented. Namely, the case study comprises the construction of a five-storey building with two options concerning the structure: Reinforced Concrete (RC building) and Steel Structure (SS building). Figure 4 represents the main activities of these two alternative buildings (Gantt charts can be found as supplemental online material as the fourth set of Figures). The project duration is 108 working days for the RC building (left) and 95 working days for the SS building (right).

<Insert Figure 4 here>

From left to right, the table columns of Figure 4 represent the activities: identifier (ID), units, description, quantities (Q), performance or expected productivity (P), duration (as Q/P), a rounded-up duration of the latter column values for the sake of simplicity, details of the technological activity precedences, the zone where each activity is performed (outdoor = influenced by the weather, indoor = not influenced by the weather), and the specific CRC to which each activity is assimilated (outdoor activities only).

Despite the authors' acknowledgement that these two buildings represent just a simplification of the large number of activities that any real building involves, this case study allows a fair representation of the method proposed. In real-life settings, therefore, the only difference would be the allocation of CRC coefficients to a longer list of activities.

4. Results

Figure 5 and 6, respectively, represent the average durations that both the RC building and the SS building would have had if they had been built in each of the Spanish capitals of province, depending also on the date (season) the projects had started, but only considering the “average” weather conditions. Namely, the duration of each activity is calculated as its original duration divided by its respective CRC, which changes according to the month(s) in which the activity is executed. Overall, in the absence of any weather consideration, the RC building required 108 working days, whereas the SS building required 95 working days. However, the real durations when taking the weather into account are invariantly longer.

<Insert Figure 5 here>

<Insert Figure 6 here>

Although these projects are relatively short in time (around 5 months) and despite only outdoor activities are exposed to the weather, projects starting in July (summer season) have the shortest project durations on average (greener cells). Conversely, projects starting in January (winter) and October (autumn) evidence the longest durations. Cities like Córdoba and Jaén have shorter project durations (as the weather was better in those locations), whereas San Sebastián has the longest durations (due to its significantly worse weather conditions).

The four last columns and rows (headed with blue-shaded colour) to the right and bottom, respectively, of each Figure 5 and 6 denote the maximum and minimum project durations (by rows and columns). They are expressed in working days and in percentage compared to the Baseline duration of each type of building.

In short, information processed as in Figures 5 and 6 constitutes a powerful planning tool. First, it anticipates how much extra time (on average) a project will take. Second, it helps in making the decision about “when” it would be best to start the project execution so that the duration (and also the costs) are minimised.

Additionally, as Figure 5 and 6 also show, although project locations in real-life cannot be easily changed, a modified project start date may offer a significant potential for productivity improvement. As it is evidenced from the above examples, in which half of the activities are not even influenced by the weather, a difference of 5% to 20% in project duration would be a reasonable expectation, most of the time.

Finally, it is worth noting that, so far, it has been assumed that both the contractor and the project owner are dealing with ready-designed buildings. In these cases, the project schedule can be elaborated in advance. Hence, the activity durations can be closely anticipated as a function of their future calendar execution times. However, in those cases where the project schedule might not follow a standard order of execution (e.g., fast tracking) and/or when the project design and specifications might not be clear from the outset (e.g., design- build contracts), numerous schedule variations (even scope variations) might take place. In these cases, it would be difficult to have access to reliable duration estimates at the early stages of the project. Obviously, all these aspects might limit the model accuracy when anticipating the future likely project duration and its optimum start date. However, and maybe paradoxically, this limitation does not affect the capability of the model in mediating conflicts arising from weather-related contractual claims.

5. Discussion

This section will be mostly devoted to the discussion of why (and how) it is possible to know whether a contractor has experienced a project delay as a consequence of the weather or of something else, and how to use the time deviation to state whether the contractor is entitled to compensation. The answer to this question is also applicable to the “average” weather conditions by which the project durations from Figures 5 and 6 have been derived. However, (stochastically) variable weather conditions will also be considered in this case. This paper promised, as a by-product of the main model, to offer a method for mediating in weather-related construction claims. To do so, the model should be applied following the steps described below.

First, the contractor should register when all the activities in the construction site are executed (start and end dates) and their precedence relationships (which ones have had to finish before the subsequent activities could start). This ‘as-built’ schedule (e.g. Gantt chart) will act as the ‘baseline’ document between the contractor and the project owner. To avoid ambiguities, it is advisable that the Work Breakdown Structure (WBS) resemble the budget items against which the progress is reported and billed. The advantage of this approach is that by establishing a coherent correspondence between progress and payments, both parties are invited to share the same progress information regarding the actual execution.

Second, on sharing a common as-built schedule, both parties should agree on the specific CRC to be allocated to each activity (whenever it is exposed to the weather). In short, this is exactly what was represented in Figure 4, but instead of doing this allocation *ex-ante*, in this occasion the allocation can also be done *ex-post*, that is, retrospectively (when the works have partially or totally finished).

Third, monthly RCC values (by equations 1 to 7) for calculating the monthly CRC values (by equations 8 to 14), from as many recent years as possible prior to the project start date, have to be calculated. Also, the monthly RCC and CRC values during project execution have to be calculated separately, preferably via an on-site weather station for more accurate results. Then, for the pre-execution period, either take the CRC monthly averages or go a little further and fit the Beta distributions described earlier.

Fourth, using the steps above, the actual duration of each activity is multiplied by its actual CRC. Since the CRC values are between 0 and 1, the result of this multiplication will be shorter activity durations. In other words, the fourth step will result in obtaining the original ‘planned’ activity durations before the weather influenced those activities. These ‘planned’ durations will be shorter than the ‘actual’ durations, except for non-weather-sensitive activities which will be the same (CRC values equal to 1for all months).

Fifth, now that the original planned project schedule has been inferred from the as-built schedule by means of the actual CRC multiplications, it is possible to calculate how long that original planned schedule would have taken to complete (or to reach the current progress stage), if the weather conditions had been like those in the years before the project started. For that, it is only necessary to ‘divide’ each activity duration by its respective (average or Beta-distributed stochastic) CRC value, as gathered before the project execution period. If the resulting overall project duration is longer than the as-built schedule, then the contractor has suffered weather conditions more adverse than the historical average. Conversely, if the as-built schedule duration is shorter, then that means that the contractor has enjoyed better-than-average weather conditions and would not be entitled to this kind of compensation. Of course, this analysis can be focussed, not only on the whole project duration, but also on the circumstances of a single activity or a subset of activities.

If the contractor and project client want to be more precise, for example, because they agreed that only exceptionally severe weather conditions (e.g. top 10% severe weather conditions) would lead to economic compensation for the contractor, they would need to resort to fully stochastic weather analysis. The underlying philosophy would be exactly the same as for the average weather analysis though. However, instead of working with “average” historical CRC values, a Monte Carlo simulation would be needed to generate multiple artificial years (each with a series of random CRC values calculated from the original Beta-distributed RCC values). By performing 10,000 simulations (iterations), sufficient potential project durations would be obtained, ordered and assigned a probability as in Figure 7. The closer as-built project duration was to a probability of zero, the more severe the weather conditions suffered; the closer to one (100%), the more lenient the weather was.

<Insert Figure 7 here>

Figure 7 represents the probability distributions obtained for the RC building (left) and the SS building (right). Coloured curves represent the project duration probability curves depending on when the project might start. Also, a fit to Fréchet distributions is provided for the sake of additional future statistical modelling. In this case, the Fréchet distribution, also known as inverse Weibull distribution, constitutes a logical candidate as it is an Extreme Value distribution for modelling maxima of events. Particularly, this distribution, along with the Gumbel distribution, are common alternatives when dealing with Stochastic Network Analysis (SNA) [52], that is, when calculating the total project duration of schedules whose activities have variable durations, such as in this case study. More simulation results and comparisons can be found as supplemental online material (fifth set of figures).

6. Conclusions

Project delays and cost overruns attributed to the weather are numerous in construction projects and this is reflected in the construction literature. However, few studies have addressed how to quantify (versus just stating or proving its connection) the precise extent to which weather variables and/or their intensities influence construction activities. Consequently, productivity forecasts are difficult to make and construction contracts that normally include weather-related clauses cannot count on objective approaches for their fair enforcement.

In this paper, multiple contributions towards improving the current situation have been presented. First, the most representative and recent research addressing the specific influences of weather on construction works were identified. Drawing on them, a series of coefficients were developed which help to anticipate weather-related productivity losses and activity duration extensions. Second, an approach was proposed to extrapolate coefficients in a wider geographic location with no weather data. Third, building on the above outcomes, a case study was presented, which demonstrated how much longer a building project can take as a consequence of location and project start date. Fourth, guidance was provided to generate stochastic Beta-distributed monthly and annual weather coefficients so that the weather conditions experienced over recent years can be modelled and reproduced during the execution stage. Fifth, a method for estimating the approximate percentile to which the real project duration corresponds in relation to the weather has also been proposed. Overall, the proposed model offers great advantages for anticipating weather-related productivity losses at the planning stage. Furthermore, during the construction phase, this method can be used to determine whether the weather conditions really entitled the contractor to compensation.

However, despite the simplicity and practicability of the model, there are some limitations. The covariances between the climatic coefficients that affect the productivity and the human dimension being affected by extreme weather events were not considered. In addition, topography considerations (e.g., the altitude) have been omitted for the sake of simplicity of the model. This was however, partially compensated by having a dense grid of available weather data. Finally, in those types of contract in which the project schedule needs to be fast tracked and/or the schedule itself cannot be easily anticipated from the outset, the ability of the proposed method for providing accurate activity duration extensions and overall project duration forecasts, as well as optimum start dates, may be limited. In spite of these limitations, the beauty of the proposed method relies on its mathematical simplicity, its wide applicability and for being the first in its kind to address the long-enduring problem of the weather-related claims in construction works.

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References

[1] A. Orangi, E. Palaneeswaran, J. Wilson, Exploring Delays in Victoria-Based Astralian Pipeline Projects, Procedia Eng. 14 (2011) 874–881. doi:10.1016/j.proeng.2011.07.111.

[2] M. Mentis, Managing project risks and uncertainties, For. Ecosyst. 2 (2015). doi:10.1186/s40663-014-0026-z.

[3] M. Głuszak, A. Lešniak, Construction Delays in Clients Opinion - Multivariate Statistical Analysis, Procedia Eng. 123 (2015) 182–189. doi:10.1016/j.proeng.2015.10.075.

[4] S.H. Kim, G. Augenbroe, Using the National Digital Forecast Database for model-based building controls, Autom. Constr. 27 (2012) 170–182. doi:10.1016/j.autcon.2012.05.012.

[5] W. Tian, P. De Wilde, Uncertainty and sensitivity analysis of building performance using probabilistic climate projections: A UK case study, Autom. Constr. 20 (2011) 1096–1109. doi:10.1016/j.autcon.2011.04.011.

[6] E. Palaneeswaran, M.M. Kumaraswamy, An integrated decision support system for dealing with time extension entitlements, Autom. Constr. 17 (2008) 425–438. doi:10.1016/j.autcon.2007.08.002.

[7] H. Tanijiri, B. Ishiguro, T. Arai, R. Yoshitake, M. Kato, Y. Morishima, N. Takasaki, Development of automated weather-unaffected building construction system, Autom. Constr. 6 (1997) 215–227. doi:10.1016/S0926-5805(97)00005-8.

[8] United States Army Construction Engineers Research Laboratory (USACERL,). Contract Duration Estimation System., 1999.

[9] D. Thorpe, E.P. Karan, Method for calculating schedule delay considering weather conditions, in: Proc. 24th Annu. ARCOM Conf. 13 Sept. 2008, Cardiff, UK, 2008: pp. 809–818.

[10] M.H. Jang, Y.S. Yoon, S.W. Suh, S.J. Ko, Method of Using Weather Information for Support to Manage Building Construction Projects (ASCE), in:

AEI 2008 Build. Integr. Solut., 2008: p. M. Ettouney (Ed.), ASCE, pp. 1–10. doi:http://dx.doi.org/10.1061/41002(328)38.

[11] A. Shahin, S.M. AbouRizk, Y. Mohamed, Modeling Weather-Sensitive Construction Activity Using Simulation, J. Constr. Eng. Manag. 137 (2011) 238–246. doi:10.1061/(ASCE)CO.1943-7862.0000258.

[12] M. Rogalska, A. Czarnigowska, Z. Hejducki, T.O. Nahurny, Methods of estimation of building processes duration including weather risk factors (in Polish), Build. Rev. 1 (2006) 37–42.

[13] The Society of Construction Law. The Society of Construction Law Delay and Disruption Protocol, 2nd ed., Wantage, Oxforshire, England, 2002. https://www.scl.org.uk/sites/default/files/SCL Delay and Disruption Protocol - subject to Rider 1.pdf.

[14] M. Jung, M. Park, H.-S. Lee, H. Kim, Weather-Delay Simulation Model Based on Vertical Weather Profile for High-Rise Building Construction, J. Constr. Eng. Manag. (2016) 4016007. doi:10.1061/(ASCE)CO.1943-7862.0001109.

[15] P. Ballesteros-pérez, M.L. Campo-hitschfeld, M.A. González-naranjo, M.C. González-cruz, Climate and construction delays: case study in Chile, Eng. Constr. Archit. Manag. 22 (2015) 596–621. doi:10.1108/ECAM-02-2015-0024.

[16] W. Hughes, P. Hillebrandt, D.G. Greenwood, W.E.K. Kwawu, Procurement in the Construction Industry: the Impact and Cost of Alternative Market and Supply Processes, London, 2006. doi:10.4324/9780203968734.

[17] J. Büdel, Büdel, J. 1982: Climatic geomorphology. Princeton: Princeton University Press. (Translation of Klima-geomorphologie, Berlin-Stuttgart: Gebrüder Borntraeger, 1977.), Prog. Phys. Geogr. 30 (2006) 99–103. doi:http://dx.doi.org/10.1191/0309133306pp473xx.

[18] O. Moselhi, K. El-Rayes, Analyzing weather-related construction claims, Cost Eng. 44 (2002) 12–19.

[19] L.D. Nguyen, J. Kneppers, B. García de Soto, W. Ibbs, Analysis of Adverse Weather for Excusable Delays, J. Constr. Eng. Manag. 136 (2010) 1258–1267. doi:10.1061/(ASCE)CO.1943-7862.0000242.

[20] K. El-Rayes, O. Moselhi, Impact of Rainfall on the Productivity of Highway Construction, J. Constr. Eng. Manag. 127 (2001) 125–131. doi:10.1061/(ASCE)0733-9364(2001)127:2(125).

[21] J. Irizarry, K.L. Simonsen, D.M. Abraham, Effect of Safety and Environmental Variables on Task Durations in Steel Erection, J. Constr. Eng. Manag. 131

(2005) 1310–1319. doi:10.1061/(ASCE)0733-9364(2005)131:12(1310).

[22] K. Yogeswaran, M.M. Kumaraswamy, D.R.A. Miller, Claims for extensions of time in civil engineering projects, Constr. Manag. Econ. 16 (1998) 283–293. doi:10.1080/014461998372312.

[23] T.J. Trauner, W.A. Manginelli, J.S. Lowe, M.F. Nagata, B.J. Furniss, Construction Delays, Understanding Them Clearly, Analyzing Them Correctly., 2009.

[24] American Concrete Institute (ACI). ACI, Manual of Concrete Practice, part 1, (1985) Detroit, Michigan, United States.

[25] Ministerio de Obras Públicas (MOP), Dirección General de Carreteras. Datos climáticos para Carreteras, (1964) Madrid, Spain 1964 (in Spanish).

[26] National Cooperative Highway Research Program (NCHRP), Effect of weather on highway construction, (1978) NCHRP Synthesis 47, Transp. Research Board.

[27] United states Army Corp of Engineers (USACE), Construction time extensions for weather, (1989) U.S. Army Corps Engineers. CEMP–CP Regulation No.4.

[28] Ministerio de Obras Públicas y Dirección de Vialidad, Manual de Carretera, Volumen 3: Instrucciones y Criterios de diseño, (2008) Santiago, Chile (in Spanish).

[29] Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT), NTP 701: Tower cranes. Safety recommendations (in Spanish), (2000).

[30] Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT), NTP 670: Scaffolds for construction works (II): set up and use (in Spanish), (2004).

[31] S. Apipattanavis, K. Sabol, K.R. Molenaar, B. Rajagopalan, Y. Xi, B. Blackard, S. Patil, Integrated Framework for Quantifying and Predicting Weather-Related Highway Construction Delays, J. Constr. Eng. Manag. 136 (2010) 1160–1168. doi:10.1061/(ASCE)CO.1943-7862.0000199.

[32] N. Hamzah, M.A. Khoiry, I. Arshad, N.M. Tawil, A.I. Che Ani, Cause of Construction Delay - Theoretical Framework, Procedia Eng. 20 (2011) 490–495. doi:10.1016/j.proeng.2011.11.192.

[33] M.M. Kumaraswamy, Conflicts, claims and disputes in construction, Eng. Constr. Archit. Manag. 4 (1997) 95–111. doi:10.1108/eb021042.

[34] M.R. Finke, Weather-related delays on government contracts, in: AACE Int. Trans. Annu. Meet. Assoc. Adv. Cost Eng. Int., 1990: p. Morgantown, WV.

[35] P. González, V. González, K. Molenaar, F. Orozco, Analysis of Causes of

Delay and Time Performance in Construction Projects, J. Constr. Eng. Manag. 140 (2014) 4013027. doi:10.1061/(ASCE)CO.1943-7862.0000721.

[36] H.R. Thomas, D.R. Riley, V.E. Sanvido, Loss of Labor Productivity due to Delivery Methods and Weather, J. Constr. Eng. Manag. 125 (1999) 39–46. doi:10.1061/(ASCE)0733-9364(1999)125:1(39).

[37] M. David, L. Adelard, P. Lauret, F. Garde, A method to generate Typical Meteorological Years from raw hourly climatic databases, Build. Environ. 45 (2010) 1722–1732. doi:10.1016/j.buildenv.2010.01.025.

[38] G. Duffy, A. Woldesenbet, “David” Hyung Seok Jeong, G.D. Oberlender, Advanced linear scheduling program with varying production rates for pipeline construction projects, Autom. Constr. 27 (2012) 99–110. doi:10.1016/j.autcon.2012.05.014.

[39] M. Dytczak, G. Ginda, N. Szklennik, T. Wojtkiewicz, Weather Influence-Aware Robust Construction Project Structure, Procedia Eng. 57 (2013) 244–253. doi:10.1016/j.proeng.2013.04.034.

[40] P. Chinowsky, A. Schweikert, N. Strzepek, K. Manahan, K. Strzepek, C.A. Schlosser, Climate change adaptation advantage for African road infrastructure, Clim. Change. 117 (2013) 345–361. doi:10.1007/s10584-012-0536-z.

[41] M. Marzouk, A. Hamdy, Quantifying weather impact on formwork shuttering and removal operation using system dynamics, KSCE J. Civ. Eng. 17 (2013) 620–626. doi:10.1007/s12205-013-0301-5.

[42] Y. Shan, P.M. Goodrum, Integration of Building Information Modeling and Critical Path Method Schedules to Simulate the Impact of Temperature and Humidity at the Project Level, Buildings. 4 (2014) 295–319. doi:10.3390/buildings4030295.

[43] M.N. Alshebani, G. Wedawatta, Making the Construction Industry Resilient to Extreme Weather: Lessons from Construction in Hot Weather Conditions, Procedia Econ.Finan. 18 (2014) 635–642. doi:10.1016/S2212-5671(14)00985-X.

[44] A. Shahin, S.M. AbouRizk, Y. Mohamed, S. Fernando, Simulation modeling of weather-sensitive tunnelling construction activities subject to cold weather, Can. J. Civ. Eng. 41 (2014) 48–55. doi:10.1139/cjce-2013-0087.

[45] X. Li, K.H. Chow, Y. Zhu, Y. Lin, Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: A case study of rebar workers, Build. Environ. 95 (2016) 42–52.

doi:10.1016/j.buildenv.2015.09.005.

[46] P. Jimenez, G. A., F. Morán, Hormigón armado, Madrid, 2001.

[47] Norma Chilena Oficial Nc. 2437 NCh, Grúas Torre. Condiciones de Operación, (1999) Instituto Nacional de Normalización. Santiago, Chile (in Spanish).

[48] Ministerio de Fomento de España, EHE 08, Instrucción Española de hormigón estructural (2008) (in Spanish).

[49] W. Yi, A.P.C. Chan, X. Wang, J. Wang, Development of an early-warning system for site work in hot and humid environments: A case study, Autom. Constr. 62 (2016) 101–113. doi:10.1016/j.autcon.2015.11.003.

[50] E. Regnier, Doing something about the weather, Omega. 36 (2008) 22–32. doi:10.1016/j.omega.2005.07.011.

[51] L. Guan, Preparation of future weather data to study the impact of climate change on buildings, Build. Environ. 44 (2009) 793–800. doi:10.1016/j.buildenv.2008.05.021.

[52] P. Ballesteros-Pérez, M-PERT. A manual project duration estimation technique for teaching scheduling basics, J. Constr. Eng. Manag. In press (2017). doi:10.1061/(ASCE)CO.1943-7862.0001358.

Reference		Construction work	(Sub) activities	Weather agents
(Thomas et al., 1999)	[36]	(Steel) Buildings	Steel structure delivery and erection activities	Temperature and Snow
(El-Rayes and Moselhi, 2001)	[20]	Highways	Earthworks, Base courses, Drainage layers and Paving	Precipitation
(Jang et al., 2008)	[10]	Buildings	Generic	Temperature and Precipitation
(Thorpe and Karan, 2008)	[9]	Buildings	Clearing and grubbing, Excavation, Foundations, Structural erection, Floors, interiors, roofs and HVAC.	Temperature, Snow, Humidity and Precipitation
(Apipattanavis et al., 2010)	[31]	Highways	Concrete and Asphalt paving, Structures, Excavations and Grading	Precipitation, Air and soil Temperature, and Wind
(David et al., 2010)	[37]	Buildings	Generic	Solar radiation, Temperature, Humidity, Wind
(Shahin et al., 2011)	[11]	Pipelines	Clearing and grading, Trenching, Bedding, Pipe-fusing, Laying-in, Hydro testing, Compaction and Backfilling	(Air and soil) Temperature, Wind, Humidity and Precipitation
(Duffy et al, 2012)	[38]	Pipelines	Grading, stringing, bending, welding, trenching, coating, lower-in, backfill, cleanup	Temperature, Wind , Precipitation
(Dytczak et al., 2013)	[39]	Buildings	Generic	Temperature and wind
(Chinowsky et al., 2013)	[40]	Roads	Generic	Temperature and Precipitation
(Marzouk and Hamdy, 2013)	[41]	Buildings	Formwork	Precipitation and Temperature
(Shan and Goodrum, 2014)	[42]	Buildings	Steel structure	Temperature and Humidity
(Alshebani and Wedawatta, 2014)	[43]	Any	Concretes, equipment-related and workers' productivity in general	(Hot) temperature
(González et al., 2014)	[35]	Buildings	(RC) structures and Finishings (e.g., partition walls, windows, and doors)	Not specified
(Shahin et al., 2014)	[44]	Tunnelling	All tunnelling process, hoisting and muck car cleaning	(Air and Soil) Temperature and Wind
(Ballesteros-pérez et al., 2015)	[15]	Bridges	Earthworks, Formworks, Concrete and Asphalt pavings	Temperature, Precipitation, wind and electrical storms
(Jung et al., 2016)	[14]	(High-rise) Buildings	Generic + core wall, steel frame, deck plate, RC, curtain wall	Solar radiation, Temperature, Wind, Dew point temperature and Precipitation
(Li et al., 2016)	[45]	(RC) Buildings	Steel reinforced bars	(Hot) temperature

Table 1. Sample of recent publications dealing with the effect of weather in construction works

Raw Climatic Coefficients (RCC) ▼		**Construction activities considered ▼**						
Monthly days without…	Mathematical expressions	**Earthworks (*E*)**	**Formworks (*F*)**	**Concrete (*C*)**	**Steelworks (*T*)**	**Scaffolding (*S*)**	**Outdoor paintings (*O*)**	**Asphalt Pavements (*P*)**
…temperatures below 0ºC (C_t^i)	$C_t^i = 1 - \frac{\textit{Days of month i with temperatures } \leq 0º\textit{C}}{\textit{Total days of month i}}$ (1)			[9,15,24,26,27,44]	[9,27,36]			[15,25–28]
…precipitation above 1 mm (C_{p1}^i)	$C_{p1}^i = 1 - \frac{\textit{Days of month i with precipitations } \geq 1\,mm}{\textit{Total days of month i}}$ (2)						[9,12]	[15,25,28]
…precipitation above 10 mm (C_{p10}^i)	$C_{p10}^i = 1 - \frac{\textit{Days of month i with precipitations } \geq 10\,mm}{\textit{Total days of month i}}$ (3)	[15,25,26,31,44]		[15,25,26,46]				
…precipitation above 30 mm (C_{p30}^i)	$C_{p30}^i = 1 - \frac{\textit{Days of month i with precipitations } \geq 30\,mm}{\textit{Total days of month i}}$ (4)				[9,15]			
…wind speed above 55 km/h (C_w^i)	$C_w^i = 1 - \frac{\textit{Days of month i with wind speed } \geq 55\,km/h}{\textit{Total days of month i}}$ (5)		[12,15,19,27,29,41, 47]	[19,27,48]	[15,19,27]	[12,19,27,30]	[19,27]	
…snow precipitation (C_s^i)	$C_s^i = 1 - \frac{\textit{Days of month i with snow precipitation}}{\textit{Total days of month i}}$ (6)	[9,11,20,44]		[9,20,24]		[9,30]	[9,30]	[20,25,28]
…electrical storm (C_e^i)	$C_e^i = 1 - \frac{\textit{Days of month i with electrical storm}}{\textit{Total days of month i}}$ (7)		[15,30]		[12,15]	[12,30]		
	Climatic Reduction Coefficients (CRC) ►	$E^i = C_{p10}^i \times C_s^i$ (8)	$F^i = C_w^i \times C_e^i$ (9)	$C^i = C_t^i \times C_{p10}^i \times \times C_w^i \times C_s^i$ (10)	$T^i = C_t^i \times C_{p30}^i \times \times C_w^i \times C_e^i$ (11)	$S^i = C_w^i \times C_s^i \times C_e^i$ (12)	$O^i = C_{p1}^i \times C_w^i \times C_s^i$ (13)	$P^i = C_t^i \times C_{p1}^i \times C_s^i$ (14)

Table 2. Monthly Climatic Reduction Coefficient calculations from the monthly Raw Climatic Coefficient values with bibliographic references

Valencia							
RCC							
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	**0.007**	-	-	0.000	0.000	-
	0.000	-	**0.002**	-	0.000	0.000	-
	0.000	-	-	**0.000**	0.000	-	0.000
	0.000	0.000	0.000	0.000	**0.003**	0.000	0.000
	0.000	0.000	0.000	-	0.000	**0.000**	0.000
	0.000	-	-	0.000	0.000	0.000	**0.002**

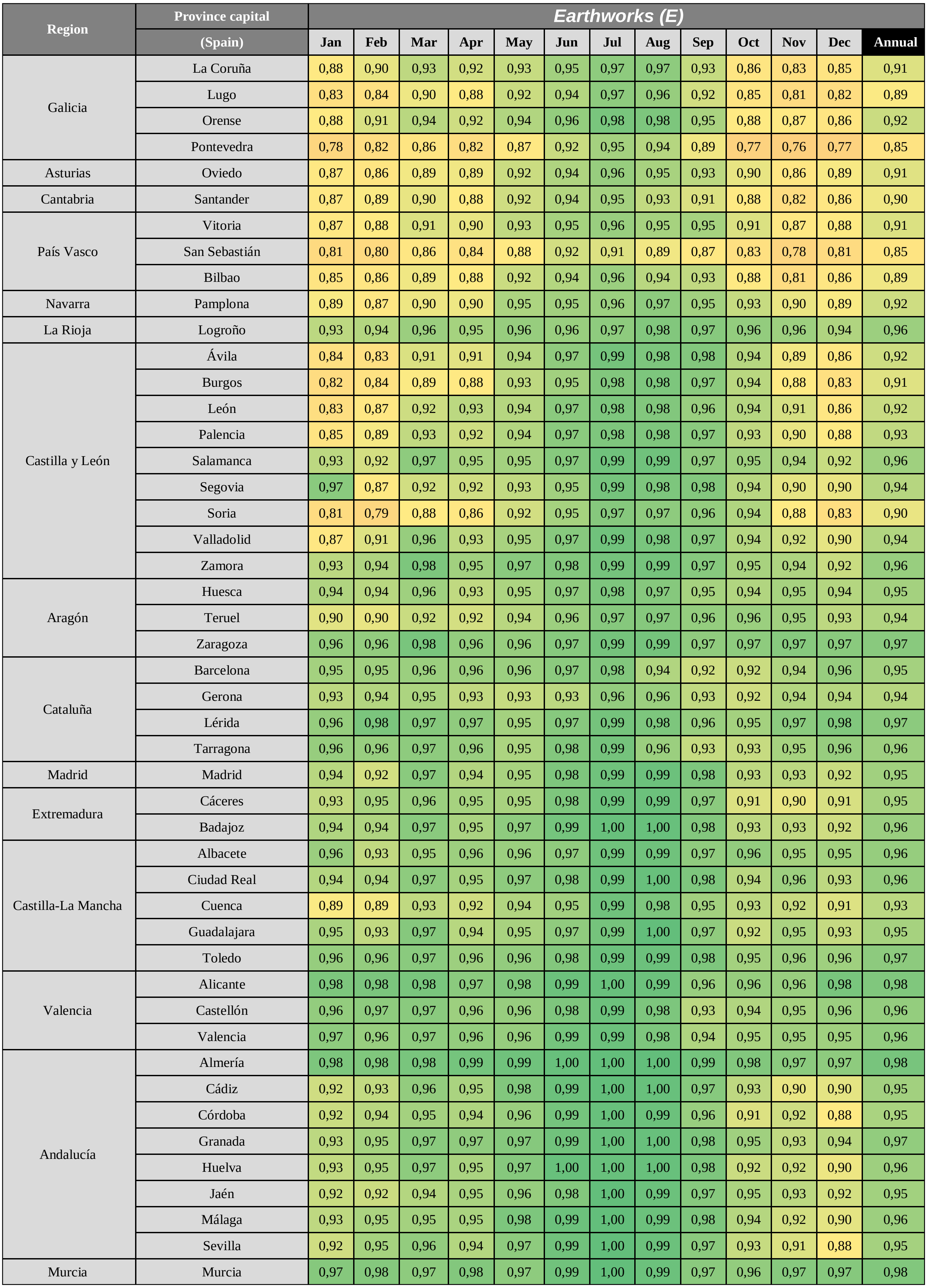
Zaragoza							
RCC							
	0.007	-0.001	0.000	0.000	0.000	0.000	0.000
	-0.001	**0.008**	-	-	-0.001	0.000	-
	0.000	-	**0.001**	-	0.000	0.000	-
	0.000	-	-	**0.000**	0.000	-	0.000
	0.000	-0.001	0.000	0.000	**0.017**	0.000	-0.001
	0.000	0.000	0.000	-	0.000	**0.000**	0.000
	0.000	-	-	0.000	-0.001	0.000	**0.002**

Madrid							
RCC							
	0.005	-0.001	0.000	0.000	0.000	0.001	0.000
	-0.001	**0.012**	-	-	0.001	0.000	-
	0.000	-	**0.002**	-	0.000	0.000	-
	0.000	-	-	**0.000**	0.000	-	0.000
	0.000	0.001	0.000	0.000	**0.002**	0.000	0.000
	0.001	0.000	0.000	-	0.000	**0.001**	0.000
	0.000	-	-	0.000	0.000	0.000	**0.002**

La Coruña							
RCC							
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	**0.023**	-	-	0.009	0.000	-
	0.000	-	**0.005**	-	0.004	0.000	-
	0.000	-	-	**0.000**	0.000	-	0.000
	0.000	0.009	0.004	0.000	**0.013**	0.000	0.001
	0.000	0.000	0.000	-	0.000	**0.000**	0.000
	0.000	-	-	0.000	0.001	0.000	**0.002**

Note: diagonal cells represent the variances, cells with “-“ represent combinations of RCC not used.

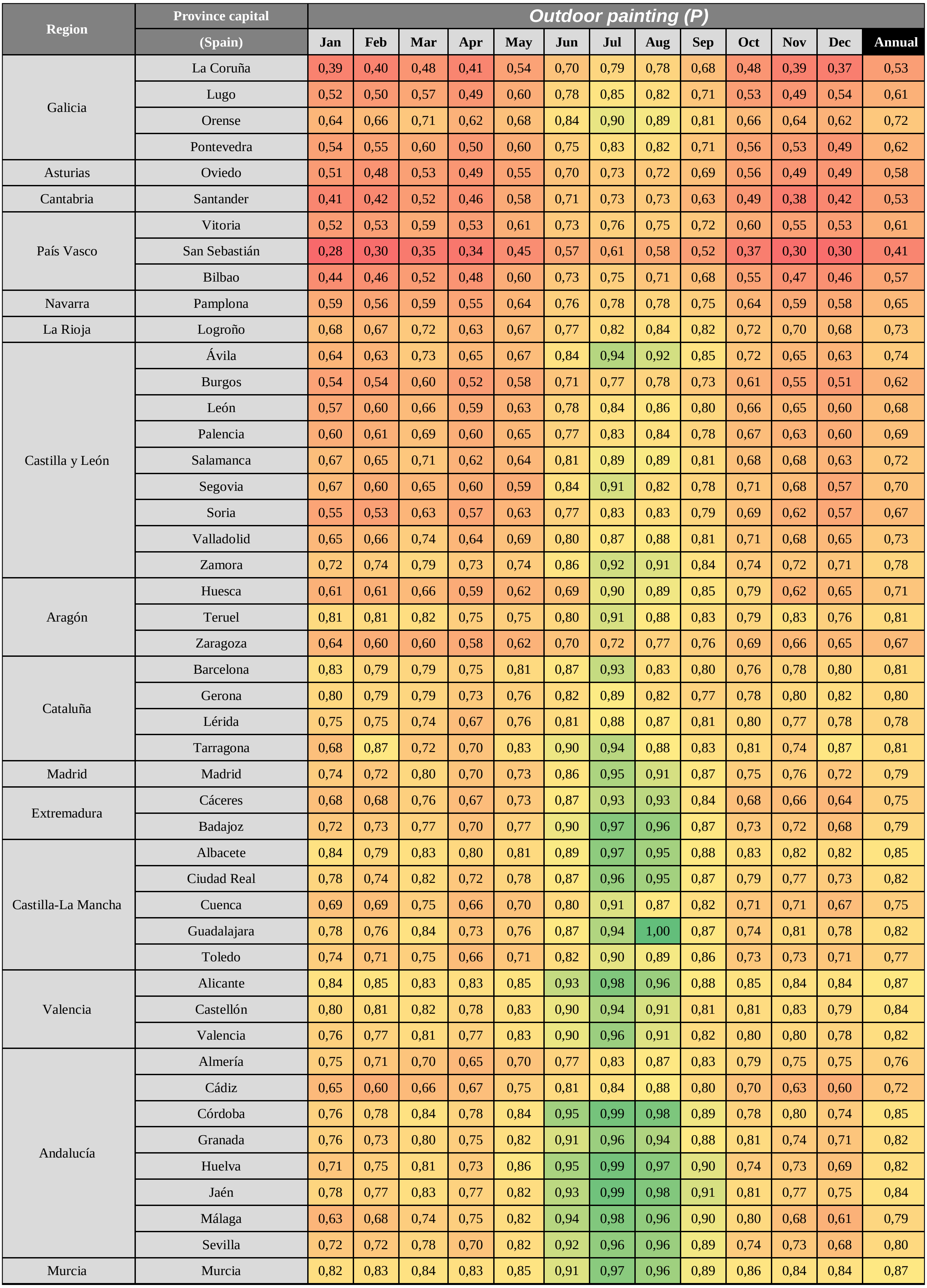
Table 3. Covariance matrices among the RCC variables for four specific Spanish locations



Region	Province capital	*Earthworks (E)*												
	(Spain)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Galicia	La Coruña	0,88	0,90	0,93	0,92	0,93	0,95	0,97	0,97	0,93	0,86	0,83	0,85	0,91
	Lugo	0,83	0,84	0,90	0,88	0,92	0,94	0,97	0,96	0,92	0,85	0,81	0,82	0,89
	Orense	0,88	0,91	0,94	0,92	0,94	0,96	0,98	0,98	0,95	0,88	0,87	0,86	0,92
	Pontevedra	0,78	0,82	0,86	0,82	0,87	0,92	0,95	0,94	0,89	0,77	0,76	0,77	0,85
Asturias	Oviedo	0,87	0,86	0,89	0,89	0,92	0,94	0,96	0,95	0,93	0,90	0,86	0,89	0,91
Cantabria	Santander	0,87	0,89	0,90	0,88	0,92	0,94	0,95	0,93	0,91	0,88	0,82	0,86	0,90
País Vasco	Vitoria	0,87	0,88	0,91	0,90	0,93	0,95	0,96	0,95	0,95	0,91	0,87	0,88	0,91
	San Sebastián	0,81	0,80	0,86	0,84	0,88	0,92	0,91	0,89	0,87	0,83	0,78	0,81	0,85
	Bilbao	0,85	0,86	0,89	0,88	0,92	0,94	0,96	0,94	0,93	0,88	0,81	0,86	0,89
Navarra	Pamplona	0,89	0,87	0,90	0,90	0,95	0,95	0,96	0,97	0,95	0,93	0,90	0,89	0,92
La Rioja	Logroño	0,93	0,94	0,96	0,95	0,96	0,96	0,97	0,98	0,97	0,96	0,96	0,94	0,96
Castilla y León	Ávila	0,84	0,83	0,91	0,91	0,94	0,97	0,99	0,98	0,98	0,94	0,89	0,86	0,92
	Burgos	0,82	0,84	0,89	0,88	0,93	0,95	0,98	0,98	0,97	0,94	0,88	0,83	0,91
	León	0,83	0,87	0,92	0,93	0,94	0,97	0,98	0,98	0,96	0,94	0,91	0,86	0,92
	Palencia	0,85	0,89	0,93	0,92	0,94	0,97	0,98	0,98	0,97	0,93	0,90	0,88	0,93
	Salamanca	0,93	0,92	0,97	0,95	0,95	0,97	0,99	0,99	0,97	0,95	0,94	0,92	0,96
	Segovia	0,97	0,87	0,92	0,92	0,93	0,95	0,99	0,98	0,98	0,94	0,90	0,90	0,94
	Soria	0,81	0,79	0,88	0,86	0,92	0,95	0,97	0,97	0,96	0,94	0,88	0,83	0,90
	Valladolid	0,87	0,91	0,96	0,93	0,95	0,97	0,99	0,98	0,97	0,94	0,92	0,90	0,94
	Zamora	0,93	0,94	0,98	0,95	0,97	0,98	0,99	0,99	0,97	0,95	0,94	0,92	0,96
Aragón	Huesca	0,94	0,94	0,96	0,93	0,95	0,97	0,98	0,97	0,95	0,94	0,95	0,94	0,95
	Teruel	0,90	0,90	0,92	0,92	0,94	0,96	0,97	0,97	0,96	0,96	0,95	0,93	0,94
	Zaragoza	0,96	0,96	0,98	0,96	0,96	0,97	0,99	0,99	0,97	0,97	0,97	0,97	0,97
Cataluña	Barcelona	0,95	0,95	0,96	0,96	0,96	0,97	0,98	0,94	0,92	0,92	0,94	0,96	0,95
	Gerona	0,93	0,94	0,95	0,93	0,93	0,93	0,96	0,96	0,93	0,92	0,94	0,94	0,94
	Lérida	0,96	0,98	0,97	0,97	0,95	0,97	0,99	0,98	0,96	0,95	0,97	0,98	0,97
	Tarragona	0,96	0,96	0,97	0,96	0,95	0,98	0,99	0,96	0,93	0,93	0,95	0,96	0,96
Madrid	Madrid	0,94	0,92	0,97	0,94	0,95	0,98	0,99	0,99	0,98	0,93	0,93	0,92	0,95
Extremadura	Cáceres	0,93	0,95	0,96	0,95	0,95	0,98	0,99	0,99	0,97	0,91	0,90	0,91	0,95
	Badajoz	0,94	0,94	0,97	0,95	0,97	0,99	1,00	1,00	0,98	0,93	0,93	0,92	0,96
Castilla-La Mancha	Albacete	0,96	0,93	0,95	0,96	0,96	0,97	0,99	0,99	0,97	0,96	0,95	0,95	0,96
	Ciudad Real	0,94	0,94	0,97	0,95	0,97	0,98	0,99	1,00	0,98	0,94	0,96	0,93	0,96
	Cuenca	0,89	0,89	0,93	0,92	0,94	0,95	0,99	0,98	0,95	0,93	0,92	0,91	0,93
	Guadalajara	0,95	0,93	0,97	0,94	0,95	0,97	0,99	1,00	0,97	0,92	0,95	0,93	0,95
	Toledo	0,96	0,96	0,97	0,96	0,96	0,98	0,99	0,99	0,98	0,95	0,96	0,96	0,97
Valencia	Alicante	0,98	0,98	0,98	0,97	0,98	0,99	1,00	0,99	0,96	0,96	0,96	0,98	0,98
	Castellón	0,96	0,97	0,97	0,96	0,96	0,98	0,99	0,98	0,93	0,94	0,95	0,96	0,96
	Valencia	0,97	0,96	0,97	0,96	0,96	0,99	0,99	0,98	0,94	0,95	0,95	0,95	0,96
Andalucía	Almería	0,98	0,98	0,98	0,99	0,99	1,00	1,00	1,00	0,99	0,98	0,97	0,97	0,98
	Cádiz	0,92	0,93	0,96	0,95	0,98	0,99	1,00	1,00	0,97	0,93	0,90	0,90	0,95
	Córdoba	0,92	0,94	0,95	0,94	0,96	0,99	1,00	0,99	0,96	0,91	0,92	0,88	0,95
	Granada	0,93	0,95	0,97	0,97	0,97	0,99	1,00	1,00	0,98	0,95	0,93	0,94	0,97
	Huelva	0,93	0,95	0,97	0,95	0,97	1,00	1,00	1,00	0,98	0,92	0,92	0,90	0,96
	Jaén	0,92	0,92	0,94	0,95	0,96	0,98	1,00	0,99	0,97	0,95	0,93	0,92	0,95
	Málaga	0,93	0,95	0,95	0,95	0,98	0,99	1,00	0,99	0,98	0,94	0,92	0,90	0,96
	Sevilla	0,92	0,95	0,96	0,94	0,97	0,99	1,00	0,99	0,97	0,93	0,91	0,88	0,95
Murcia	Murcia	0,97	0,98	0,97	0,98	0,97	0,99	1,00	0,99	0,97	0,96	0,97	0,97	0,98

Note: values closer to 1.00 represented in green. Lower values progressively represented in yellow and lowest in red.

Figure 1. Annual and monthly Earthworks average CRC values of Spanish peninsular capital of province cities.



Region	Province capital	Outdoor painting (P)												
	(Spain)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Galicia	La Coruña	0,39	0,40	0,48	0,41	0,54	0,70	0,79	0,78	0,68	0,48	0,39	0,37	0,53
	Lugo	0,52	0,50	0,57	0,49	0,60	0,78	0,85	0,82	0,71	0,53	0,49	0,54	0,61
	Orense	0,64	0,66	0,71	0,62	0,68	0,84	0,90	0,89	0,81	0,66	0,64	0,62	0,72
	Pontevedra	0,54	0,55	0,60	0,50	0,60	0,75	0,83	0,82	0,71	0,56	0,53	0,49	0,62
Asturias	Oviedo	0,51	0,48	0,53	0,49	0,55	0,70	0,73	0,72	0,69	0,56	0,49	0,49	0,58
Cantabria	Santander	0,41	0,42	0,52	0,46	0,58	0,71	0,73	0,73	0,63	0,49	0,38	0,42	0,53
País Vasco	Vitoria	0,52	0,53	0,59	0,53	0,61	0,73	0,76	0,75	0,72	0,60	0,55	0,53	0,61
	San Sebastián	0,28	0,30	0,35	0,34	0,45	0,57	0,61	0,58	0,52	0,37	0,30	0,30	0,41
	Bilbao	0,44	0,46	0,52	0,48	0,60	0,73	0,75	0,71	0,68	0,55	0,47	0,46	0,57
Navarra	Pamplona	0,59	0,56	0,59	0,55	0,64	0,76	0,78	0,78	0,75	0,64	0,59	0,58	0,65
La Rioja	Logroño	0,68	0,67	0,72	0,63	0,67	0,77	0,82	0,84	0,82	0,72	0,70	0,68	0,73
Castilla y León	Ávila	0,64	0,63	0,73	0,65	0,67	0,84	0,94	0,92	0,85	0,72	0,65	0,63	0,74
	Burgos	0,54	0,54	0,60	0,52	0,58	0,71	0,77	0,78	0,73	0,61	0,55	0,51	0,62
	León	0,57	0,60	0,66	0,59	0,63	0,78	0,84	0,86	0,80	0,66	0,65	0,60	0,68
	Palencia	0,60	0,61	0,69	0,60	0,65	0,77	0,83	0,84	0,78	0,67	0,63	0,60	0,69
	Salamanca	0,67	0,65	0,71	0,62	0,64	0,81	0,89	0,89	0,81	0,68	0,68	0,63	0,72
	Segovia	0,67	0,60	0,65	0,60	0,59	0,84	0,91	0,82	0,78	0,71	0,68	0,57	0,70
	Soria	0,55	0,53	0,63	0,57	0,63	0,77	0,83	0,83	0,79	0,69	0,62	0,57	0,67
	Valladolid	0,65	0,66	0,74	0,64	0,69	0,80	0,87	0,88	0,81	0,71	0,68	0,65	0,73
	Zamora	0,72	0,74	0,79	0,73	0,74	0,86	0,92	0,91	0,84	0,74	0,72	0,71	0,78
Aragón	Huesca	0,61	0,61	0,66	0,59	0,62	0,69	0,90	0,89	0,85	0,79	0,62	0,65	0,71
	Teruel	0,81	0,81	0,82	0,75	0,75	0,80	0,91	0,88	0,83	0,79	0,83	0,76	0,81
	Zaragoza	0,64	0,60	0,60	0,58	0,62	0,70	0,72	0,77	0,76	0,69	0,66	0,65	0,67
Cataluña	Barcelona	0,83	0,79	0,79	0,75	0,81	0,87	0,93	0,83	0,80	0,76	0,78	0,80	0,81
	Gerona	0,80	0,79	0,79	0,73	0,76	0,82	0,89	0,82	0,77	0,78	0,80	0,82	0,80
	Lérida	0,75	0,75	0,74	0,67	0,76	0,81	0,88	0,87	0,81	0,80	0,77	0,78	0,78
	Tarragona	0,68	0,87	0,72	0,70	0,83	0,90	0,94	0,88	0,83	0,81	0,74	0,87	0,81
Madrid	Madrid	0,74	0,72	0,80	0,70	0,73	0,86	0,95	0,91	0,87	0,75	0,76	0,72	0,79
Extremadura	Cáceres	0,68	0,68	0,76	0,67	0,73	0,87	0,93	0,93	0,84	0,68	0,66	0,64	0,75
	Badajoz	0,72	0,73	0,77	0,70	0,77	0,90	0,97	0,96	0,87	0,73	0,72	0,68	0,79
Castilla-La Mancha	Albacete	0,84	0,79	0,83	0,80	0,81	0,89	0,97	0,95	0,88	0,83	0,82	0,82	0,85
	Ciudad Real	0,78	0,74	0,82	0,72	0,78	0,87	0,96	0,95	0,87	0,79	0,77	0,73	0,82
	Cuenca	0,69	0,69	0,75	0,66	0,70	0,80	0,91	0,87	0,82	0,71	0,71	0,67	0,75
	Guadalajara	0,78	0,76	0,84	0,73	0,76	0,87	0,94	1,00	0,87	0,74	0,81	0,78	0,82
	Toledo	0,74	0,71	0,75	0,66	0,71	0,82	0,90	0,89	0,86	0,73	0,73	0,71	0,77
Valencia	Alicante	0,84	0,85	0,83	0,83	0,85	0,93	0,98	0,96	0,88	0,85	0,84	0,84	0,87
	Castellón	0,80	0,81	0,82	0,78	0,83	0,90	0,94	0,91	0,81	0,81	0,83	0,79	0,84
	Valencia	0,76	0,77	0,81	0,77	0,83	0,90	0,96	0,91	0,82	0,80	0,80	0,78	0,82
Andalucía	Almería	0,75	0,71	0,70	0,65	0,70	0,77	0,83	0,87	0,83	0,79	0,75	0,75	0,76
	Cádiz	0,65	0,60	0,66	0,67	0,75	0,81	0,84	0,88	0,80	0,70	0,63	0,60	0,72
	Córdoba	0,76	0,78	0,84	0,78	0,84	0,95	0,99	0,98	0,89	0,78	0,80	0,74	0,85
	Granada	0,76	0,73	0,80	0,75	0,82	0,91	0,96	0,94	0,88	0,81	0,74	0,71	0,82
	Huelva	0,71	0,75	0,81	0,73	0,86	0,95	0,99	0,97	0,90	0,74	0,73	0,69	0,82
	Jaén	0,78	0,77	0,83	0,77	0,82	0,93	0,99	0,98	0,91	0,81	0,77	0,75	0,84
	Málaga	0,63	0,68	0,74	0,75	0,82	0,94	0,98	0,96	0,90	0,80	0,68	0,61	0,79
	Sevilla	0,72	0,72	0,78	0,70	0,82	0,92	0,96	0,96	0,89	0,74	0,73	0,68	0,80
Murcia	Murcia	0,82	0,83	0,84	0,83	0,85	0,91	0,97	0,96	0,89	0,86	0,84	0,84	0,87

Note: values closer to 1.00 represented in green. Lower values progressively represented in yellow and lowest in red.

Figure 2. Annual and monthly Outdoor Paintings average CRC values of Spanish peninsular capital of province cities.

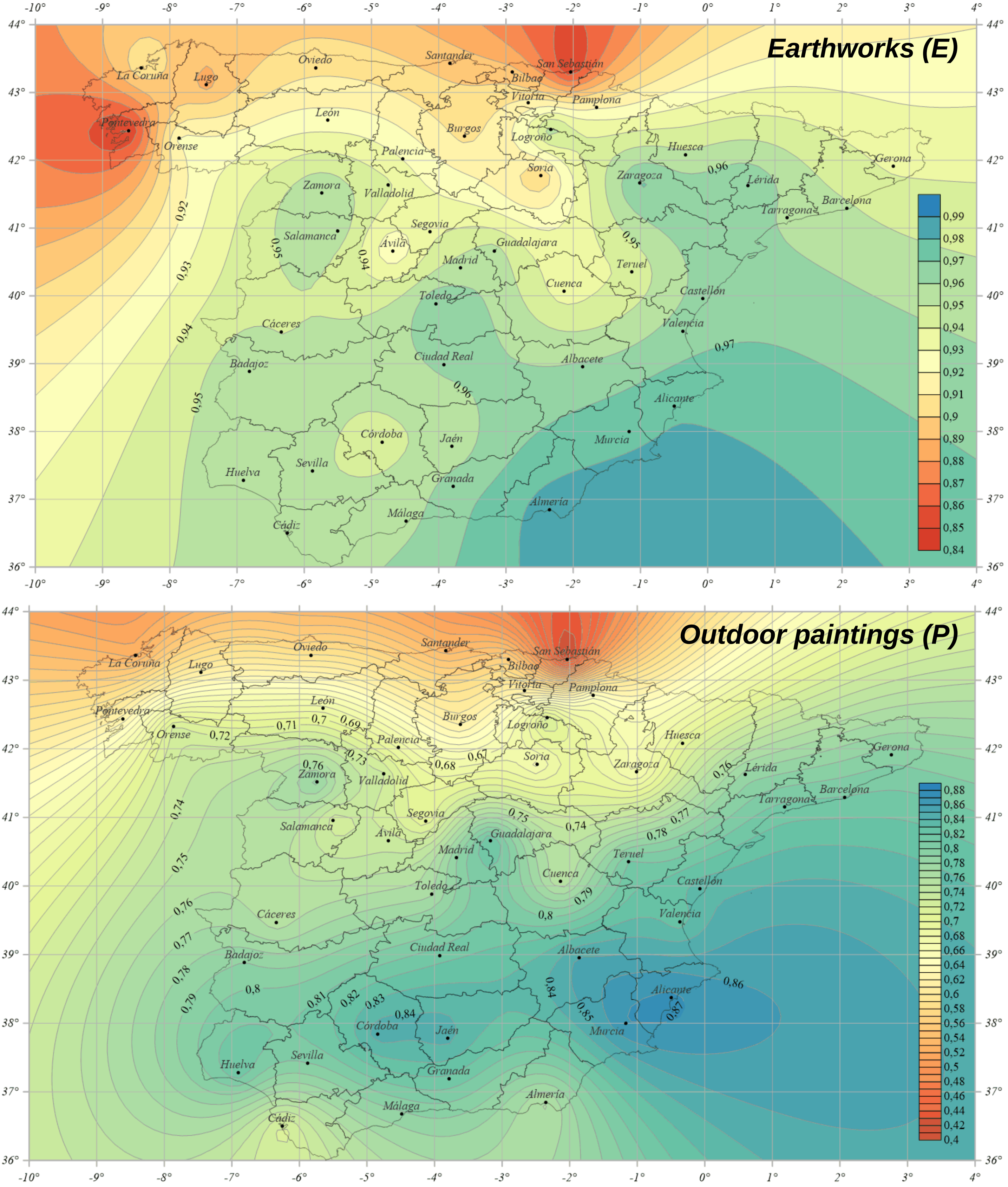


Figure 3. Sample of Earthworks and Outdoor Painting annual CRC values maps

5-storey reinforced concrete (RC) building

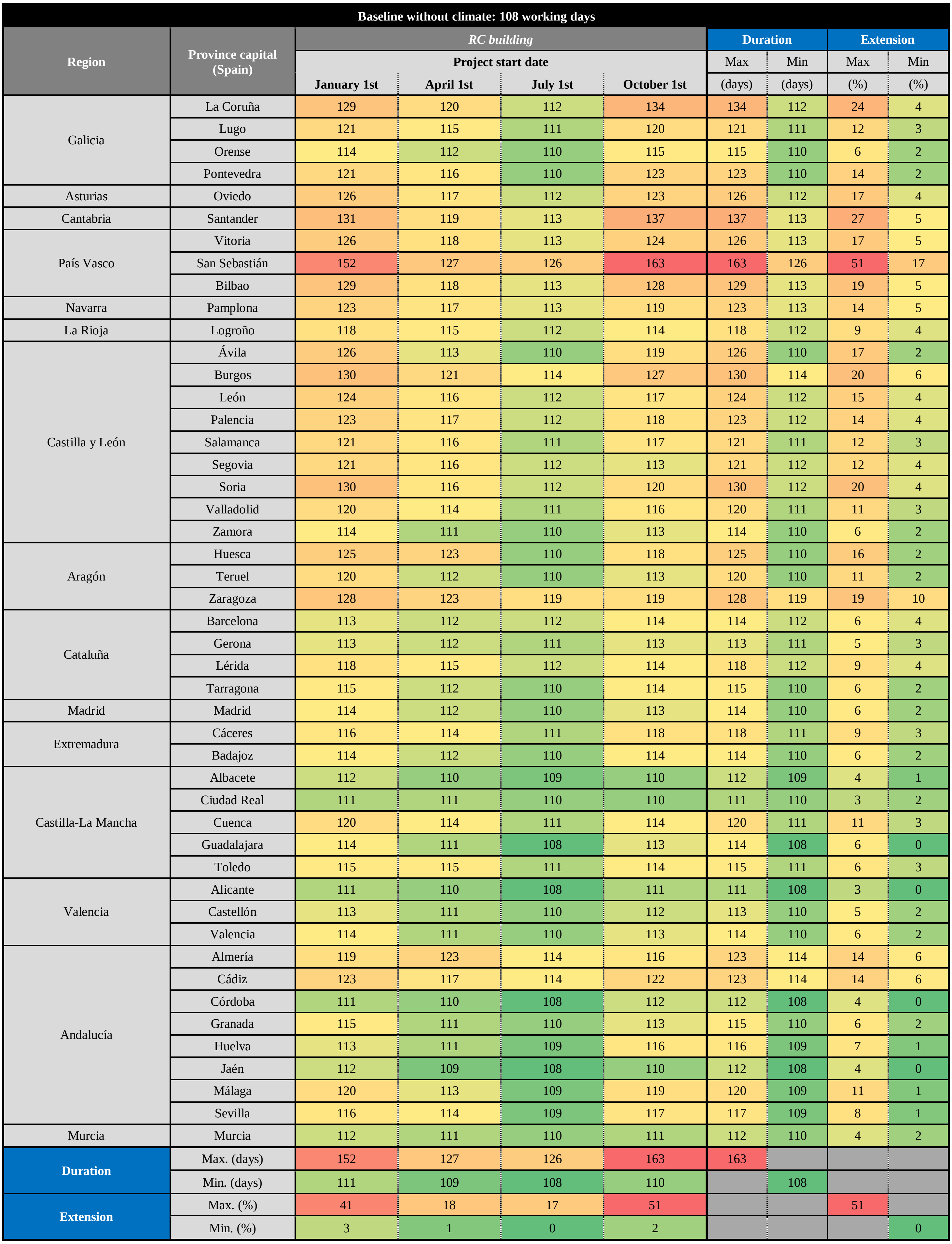
ID	Unit	Activity (description)	Quantity (Q) (# units)	Performance (P) (# units/ day)	Duration (Q/P) (exact # days)	Real Duration (RD) (rounded-up/down days)	Predecessor (ID+relation+lag)	Zone (Outdoor/Indoor)	CRC (identification)
1. Structural works									
1.1	gl	Site marking (*)	1	1.00	1.00	1	Start	Outdoor	E
1.2	m3	Excavations	117	20.00	5.85	6	1.1FS	Outdoor	E
1.3	m3	Lean concrete	40	40.00	1.00	1	1.2FS	Outdoor	C
1.4	kg	Reinforcing steel	27000	720.00	37.50	38	1.3FS	Outdoor	T
1.5	m3	Concrete (foundations)	59	35.00	1.69	2	1.4SS+5%	Outdoor	C
1.6	m2	Formworks	2800	85.00	32.94	33	1.5FS	Outdoor	F
1.7	m3	Structural concrete	307	10.00	30.70	31	1.6SS+10%	Outdoor	C
1.8	m2	Roof (**)	360	18.00	20.00	20	1.7FS	Outdoor	S
1.9	m2	Scaffolding	1200	80.00	15.00	15	1.7FS	Outdoor	S
2. Finishings									
2.1	m2	Outdoor paint coating	764	40.00	19.10	19	1.9SS+25%	Outdoor	O
2.2	m2	Plastering	1665	50.00	33.30	33	1.7FS	Indoor	-
2.3	gl	Doors and windows installation	1	0.05	20.00	20	2.4FS	Indoor	-
2.4	m2	Partitions and cladding	1280	38.00	33.68	34	1.7FS	Indoor	-
2.5	m2	Indoor paint coating	2300	70.00	32.86	33	2.4SS+20%	Indoor	-
2.6	m2	Suspended ceilings	1150	35.00	32.86	33	2.5SS+20%	Indoor	-
2.7	m2	Floors	1150	35.00	32.86	33	2.6SS+20%	Indoor	-
2.8	gl	Moldings	1	0.05	20.00	20	2.7SS+50%	Indoor	-
2.9	gl	Other minor finishings	1	0.05	20.00	20	2.8SS+20%	Indoor	-
3. Installations									
3.1	gl	Electrical works	1	0.05	20.00	20	2.7SS+30%	Indoor	-
3.2	gl	Furnishing and fixture installation	1	0.05	20.00	20	2.7SS+30%	Indoor	-
3.3	gl	Plumbing domiciliary works	1	0.02	50.00	50	1.3FS	Indoor	-

5-storey reinforced concre

ID	Unit	
1. Structural works		
1.1	gl	Site marki
1.2	m3	Excavatio
1.3	m3	Lean conc
1.4	kg	Reinforci
1.5	m3	Concrete
1.6	m2	Formwork
1.7	m3	Structural
1.8	m2	Roof (**)
1.9	m2	Scaffoldin
2. Finishings		
2.1	m2	Outdoor p
2.2	m2	Plastering
2.3	gl	Doors an
2.4	m2	Partitions
2.5	m2	Indoor pa
2.6	m2	Suspended
2.7	m2	Floors
2.8	gl	Moldings
2.9	gl	Other mi
3. Installations		
3.1	gl	Electrical
3.2	gl	Furnishing
3.3	gl	Plumbing

* Assimilated to Earthworks CRC ** Assimilated to Scaffolding CRC *** Assimilated to Formworks CRC

Figure 4. 5-storey Reinforced Concrete (left) and Steel Structure (right) building project activities



Baseline without climate: 108 working days									
Region	**Province capital (Spain)**	***RC building***				**Duration**		**Extension**	
		Project start date				Max	Min	Max	Min
		January 1st	**April 1st**	**July 1st**	**October 1st**	(days)	(days)	(%)	(%)
Galicia	La Coruña	129	120	112	134	134	112	24	4
	Lugo	121	115	111	120	121	111	12	3
	Orense	114	112	110	115	115	110	6	2
	Pontevedra	121	116	110	123	123	110	14	2
Asturias	Oviedo	126	117	112	123	126	112	17	4
Cantabria	Santander	131	119	113	137	137	113	27	5
País Vasco	Vitoria	126	118	113	124	126	113	17	5
	San Sebastián	152	127	126	163	163	126	51	17
	Bilbao	129	118	113	128	129	113	19	5
Navarra	Pamplona	123	117	113	119	123	113	14	5
La Rioja	Logroño	118	115	112	114	118	112	9	4
Castilla y León	Ávila	126	113	110	119	126	110	17	2
	Burgos	130	121	114	127	130	114	20	6
	León	124	116	112	117	124	112	15	4
	Palencia	123	117	112	118	123	112	14	4
	Salamanca	121	116	111	117	121	111	12	3
	Segovia	121	116	112	113	121	112	12	4
	Soria	130	116	112	120	130	112	20	4
	Valladolid	120	114	111	116	120	111	11	3
	Zamora	114	111	110	113	114	110	6	2
Aragón	Huesca	125	123	110	118	125	110	16	2
	Teruel	120	112	110	113	120	110	11	2
	Zaragoza	128	123	119	119	128	119	19	10
Cataluña	Barcelona	113	112	112	114	114	112	6	4
	Gerona	113	112	111	113	113	111	5	3
	Lérida	118	115	112	114	118	112	9	4
	Tarragona	115	112	110	114	115	110	6	2
Madrid	Madrid	114	112	110	113	114	110	6	2
Extremadura	Cáceres	116	114	111	118	118	111	9	3
	Badajoz	114	112	110	114	114	110	6	2
Castilla-La Mancha	Albacete	112	110	109	110	112	109	4	1
	Ciudad Real	111	111	110	110	111	110	3	2
	Cuenca	120	114	111	114	120	111	11	3
	Guadalajara	114	111	108	113	114	108	6	0
	Toledo	115	115	111	114	115	111	6	3
Valencia	Alicante	111	110	108	111	111	108	3	0
	Castellón	113	111	110	112	113	110	5	2
	Valencia	114	111	110	113	114	110	6	2
Andalucía	Almería	119	123	114	116	123	114	14	6
	Cádiz	123	117	114	122	123	114	14	6
	Córdoba	111	110	108	112	112	108	4	0
	Granada	115	111	110	113	115	110	6	2
	Huelva	113	111	109	116	116	109	7	1
	Jaén	112	109	108	110	112	108	4	0
	Málaga	120	113	109	119	120	109	11	1
	Sevilla	116	114	109	117	117	109	8	1
Murcia	Murcia	112	111	110	111	112	110	4	2
Duration	Max. (days)	152	127	126	163	163			
	Min. (days)	111	109	108	110		108		
Extension	Max. (%)	41	18	17	51			51	
	Min. (%)	3	1	0	2				0

Note: Lowest durations represented in green. Highest durations represented in red. Medium durations in yellow/orange.

Figure 5. Calculations of the average 5-storey Reinforced Concrete (RC) building project duration extension in Spain.

Baseline without climate: 95 working days										
Region	**Province capital (Spain)**	***SS building***				**Duration**		**Extension**	
		Project start date				Max	Min	Max	Min
		January 1st	**April 1st**	**July 1st**	**October 1st**	(days)	(days)	(%)	(%)
Galicia	La Coruña	108	104	96	109	109	96	15	1
	Lugo	103	99	96	101	103	96	8	1
	Orense	98	97	95	98	98	95	3	0
	Pontevedra	103	100	96	103	103	96	8	1
Asturias	Oviedo	106	103	96	102	106	96	12	1
Cantabria	Santander	109	102	97	111	111	97	17	2
País Vasco	Vitoria	107	103	97	105	107	97	13	2
	San Sebastián	123	109	103	125	125	103	32	8
	Bilbao	107	103	97	107	107	97	13	2
Navarra	Pamplona	104	102	99	101	104	99	9	4
La Rioja	Logroño	100	100	97	97	100	97	5	2
Castilla y León	Ávila	107	98	95	99	107	95	13	0
	Burgos	109	104	99	103	109	99	15	4
	León	105	101	96	98	105	96	11	1
	Palencia	105	102	96	99	105	96	11	1
	Salamanca	103	101	96	98	103	96	8	1
	Segovia	102	102	96	97	102	96	7	1
	Soria	109	102	96	99	109	96	15	1
	Valladolid	103	98	96	98	103	96	8	1
	Zamora	98	96	95	97	98	95	3	0
Aragón	Huesca	106	103	95	99	106	95	12	0
	Teruel	103	97	95	96	103	95	8	0
	Zaragoza	106	104	101	102	106	101	12	6
Cataluña	Barcelona	97	97	96	98	98	96	3	1
	Gerona	97	96	96	98	98	96	3	1
	Lérida	100	99	96	97	100	96	5	1
	Tarragona	98	97	96	99	99	96	4	1
Madrid	Madrid	98	97	95	97	98	95	3	0
Extremadura	Cáceres	99	98	96	100	100	96	5	1
	Badajoz	97	97	95	97	97	95	2	0
Castilla-La Mancha	Albacete	97	96	95	96	97	95	2	0
	Ciudad Real	97	96	95	96	97	95	2	0
	Cuenca	102	98	96	97	102	96	7	1
	Guadalajara	99	96	95	97	99	95	4	0
	Toledo	98	100	96	97	100	96	5	1
Valencia	Alicante	96	96	95	96	96	95	1	0
	Castellón	97	96	95	96	97	95	2	0
	Valencia	97	96	95	97	97	95	2	0
Andalucía	Almería	102	104	97	98	104	97	9	2
	Cádiz	104	99	97	103	104	97	9	2
	Córdoba	97	96	95	97	97	95	2	0
	Granada	98	96	96	97	98	96	3	1
	Huelva	97	96	95	98	98	95	3	0
	Jaén	97	96	95	96	97	95	2	0
	Málaga	103	97	95	99	103	95	8	0
	Sevilla	99	98	95	99	99	95	4	0
Murcia	Murcia	96	96	95	96	96	95	1	0
Duration	Max. (days)	123	109	103	125	125			
	Min. (days)	96	96	95	96		95		
Extension	Max. (%)	29	15	8	32			32	
	Min. (%)	1	1	0	1				0

Note: Lowest durations represented in green. Highest durations represented in red. Medium durations in yellow/orange.

Figure 6. Calculations of the average 5-storey Steel Structure (SS) building project duration extension in Spain.

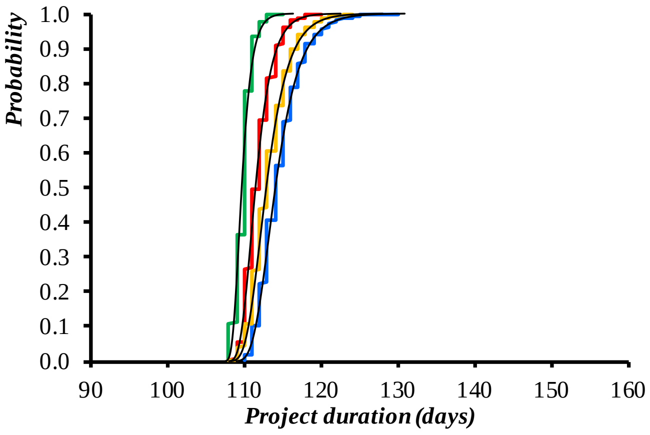
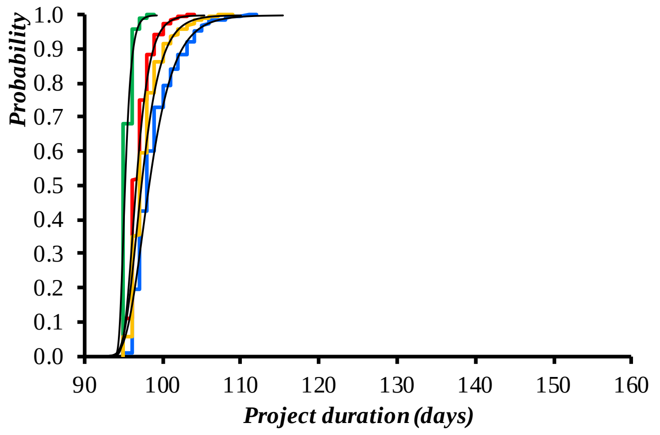
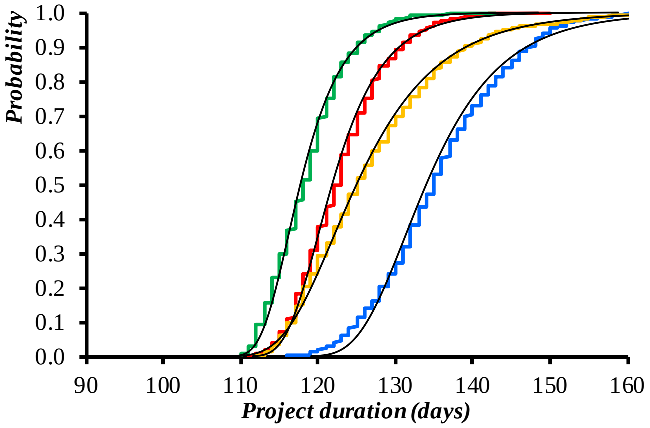
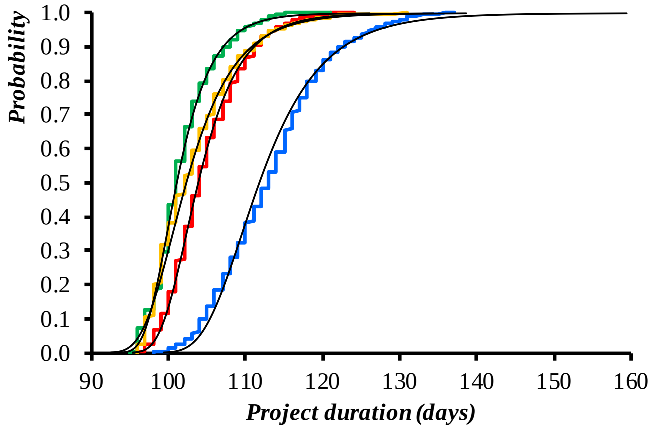
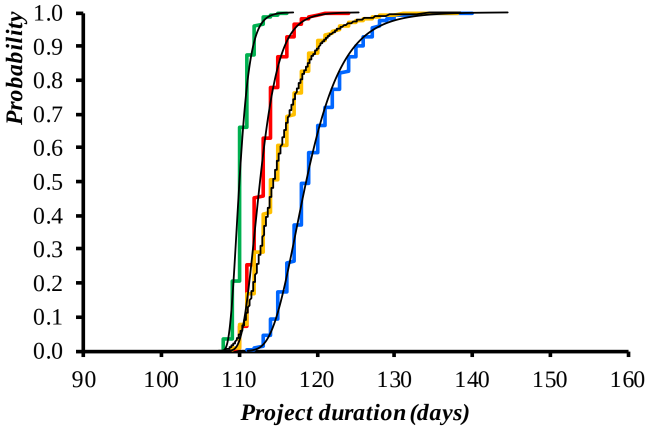
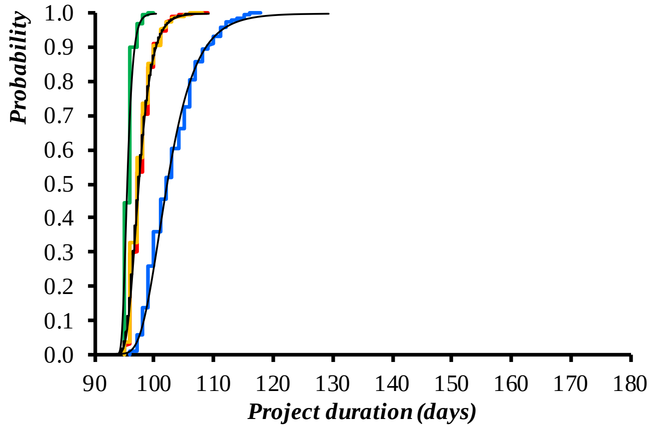
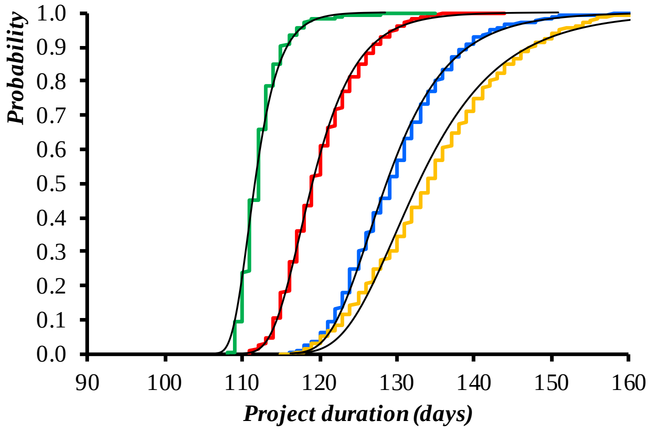
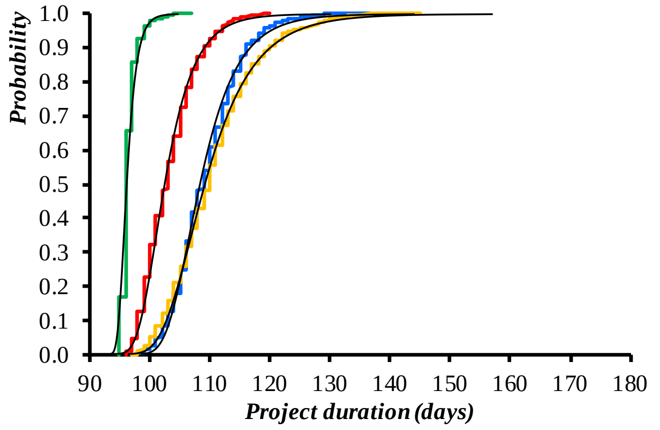
City	**RC building** *(Baseline without climate 108 working days)*	**SS building** *(Baseline without climate 95 working days)*
Valencia		
Zaragoza		
Madrid		
La Coruña		
Project Start date: — January 1st — April 1st — July 1st — October 1st — Fréchet fit		

Figure 7. Concrete (RC) and Steel structure (SS) building actual values and stochastic simulations