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The effect on cost when utilising modular construction techniques - The impact of weather on labour productivity

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ABSTRACT

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The Main running ain of this paper is to explore the impact weather will have on labour productivity costs associated with construction activities that would be replaced by using modular production techniques. Weather is a cost variable that is often ignored during pricing of construction projects and is rarely recorded as a cost impact, and yet the impact can be considerable if not planned appropriately. Modular construction is a form of off-site construction that creates a three-dimensional section if a building in a factory and transports it to site, the quantity of the build that is replaced with the modules can vary and so assumptions have been made on the elements of traditional construction that have been replaced. The weather impact has been based on UK weather data and the focus has been on those that will affect labour productivity in particular, such as high temperatures, low temperatures, precipitation, and wind. The paper has analysed the impact start date and length of project will have on particular weather types occurring during a project and applying those to assumed productivity reduction that comes from those weather types.

Keywords: weather; modular; construction; cost; productivity

Introduction

The relationship between weather and productivity is complex, and yet is often identified as one of the top causes for delays and subsequent cost increases [1]. This paper aims to quantify this impact, however due to the unpredictable nature of weather, assumptions will need to be made. As weather has been shown to have a significant impact on productivity in certain situations, removing the weather variable should have a subsequent positive impact. Offsite construction is an overarching term used to cover many of the different process where parts of a construction project are manufactured in a factory and then transported and installed onsite, this paper will focus on modular production which is the three-dimensional aspect of offsite. The principal hypothesis of this research is that by using more modular techniques, producing build elements in a factory environment which has a controlled environment, will

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reduce the impact of weather as a cost on that project, over the cost that would occur in the traditional labour-intensive production method.

The nature of human interaction with the built and natural environment, further complicates the quantification of productivity [2, 3], for example some people cope well working in cold or hot conditions, some people will suffer more from emotional impact of different weather types etc. Many studies have been carried out on weather impact for technical productivity, but due to complexities listed above, amongst others, impact on labour productivity is often not considered [1]. High temperatures are becoming more prevalent worldwide (See Figure 2), with temperatures currently expected to rise by over 2°C. Some of the issues caused by extreme heat (classed as over 25°C) include dust created by dry soil that can affect properties and the health of occupants in neighbouring properties, as well as the construction workers themselves. Labour productivity is reduced due to the difficulties working in these temperatures and the need for more breaks and fluid intake. There is also the risk to human life with rising cases of heat stress. Moohialdin et al. [4] stated that a variance of up to 64% in productivity is possible due to high or low temperatures. and for every 1°C rise above 28°C that is seen, a reduction in productivity was noted at up to 57%.

Although offsite has been used successfully in some projects it still has not made an industry wide impact [5] The most impact would be seen by maximising factory production with modular construction, where a three dimensional (3D) portion of the build is manufactured in a factory, transported to the site and installed [5].

Modular production techniques have many benefits including speed of production, quality of build etc, however there are also some drawbacks such as limited supply chain and lack of flexibility in both design and supply. The cost impact of modular construction is still being debated, and as Modules are manufactured in a controlled environment, they are less affected by onsite weather conditions and so there should be a comparative reduction in cost.

Literature Review

Modular Production

With so many difficulties impacting on the construction industry, some stating a perfect storm is imminent [6], it is imperative that a new method of production is found to alleviate some of these issues. Some of the key issues being highlighted by industry academics and leaders include, lack of skilled labour, reductions in profit margin, lack of sustainable materials, low productivity, etc. Another issue which has been raised is the impact of weather on productivity [7]. One of the solutions for these industry wide global issues is a move to a more offsite production process, where manufacturing processes in a protected and controlled environment for part of the project productivity thereby reducing the impact of weather still today [8] amongst other benefits.

Traditional construction involves the production of buildings and infrastructure almost entirely on-site using heavily labour-intensive techniques (having high labour costs per unit of output) [9], and while there is an impact on material and plant productivity from weather, the greatest impact is on labour [10]. Practitioners are more often considering weather from a need to adjust working practices and having sufficient control and allocated risk within the contract [1]. Practitioners rarely take into account the impact of weather [11], often there is insufficient time during the tender process to take it into account, and there is insufficient data available to make the prediction on cost impact [12].

In construction contracts, extreme weather can be dealt with as Force Majeure clauses and Extension of Time and Loss and expense claims [13]. Financial implications of weather are rarely considered for non-extreme weather, as the client would not normally bear the loss, the main contractor would often pass losses down the supply chain, and subcontractors will not push a standard weather claim due to the need for work continuity [11].

The barriers to the use of off-site in the UK include public negative perception, preparation issues, cost and equipment issues, whereas the advantages are seen as including productivity improvements, time savings, labour savings, environmental improvements and improved quality [14]. The United Kingdom is very commercially aware and therefore cost is likely to be a more important driver for development and production changes than family use and utilisation or aesthetics as may be seen in other cultures or countries [14].

Despite all the advantages the UK housing sector remains dominated by traditional construction techniques [15], We are, however approaching a crisis point, particularly in relation to a skills shortage [6] that may force a change to Modular and other off-site techniques.

The main areas of concern for contractors considering a move into more off site production methods were with higher costs and lack of flexibility in [16], as well as long lead in times and a small supply chain that is not capable, in its present state to keep up with demand [17] and has not grown significantly in the 11 years up to 2018 [18].

Much of the research carried out to date that discusses cost ([19, 20] etc) explores the production, logistics and installation costs associated with a comparison between modular and traditional construction, a few ([20, 21] etc) suggest there is more to the costing than just these elements but there is little concrete research into the cost variables and their impact on product selection [22].

Some of the variables listed in research that can be included in the cost model include economy of scale [23, 24], Reduced Labour congestion on site making for more efficient productivity [24, 21], Overhead reduction due to shorter on site construction, weather avoidance reducing delay potential, design standardisation and energy reduction in both the production and use phase [20, 24].

Construction costs are typically between 43 and 46% of overall costs [25, 26], which is why much of existing research focusses on this area, in Modular construction this will include manufacturing costs, transportation costs as well as on site costs [27].

When working in a factory environment there is a more protected atmosphere, and a more controllable atmosphere, and this will have an impact on improved welfare, greater productivity and reduced health and safety costs (loss of workdays due to ill health and accident) [28]. The greater control comes from having a production facility that is contained and can have more direct supervision [29], as opposed to a construction site that is often quite spread out, particularly on the larger developments.

Studies have shown the main benefits to using off-site construction include productivity, (within which the production speed over the entire project is listed as the highest factor), improved quality, lower costs and lower onsite labour [30]. It is evidence of the complexity of the cost issue to see various studies listing cost as both a barrier and a benefit. Increased worker safety is also presented in literature as a benefit [31], as is the reduction of ecological impact, Improvements in waste reduction and collection and an overall increase in health and safety standards.

The main barriers to the use of off-site production to include cost, which is often listed as the most relevant, lack of cost certainty, lack of expertise, new technical requirements and knowledge, lack of research and development, logistical difficulties and a reluctance within the industry to move away from what is known [16].

Cost Variables

Cost is one of the most important decisions in production techniques, and weather has been shown to have a potential impact on productivity [1], if the impact of weather can be removed or reduced then this will have a positive impact on cost, this cost variable is therefore the focus of this paper. By exploring some of the key cost variables that impact on traditional construction costs ([22], more clarity will be developed, and this should lead to less reluctance in the use of Modular production. The cost variables are numerous and vary in complexity [22]. Some of these variables can easily be monetised such as preliminaries and construction costs, whereas others are harder to cost, such as implications of quality improvements [22]. The impact of weather is reasonably well researched, with 45% of projects worldwide being affected by Weather [32] but limited in terms of cost impact. It is also important to note that costs are typically carried by all stakeholders on a project to varying degrees, not just the contractor, and the industry expects delays in a project and therefore the related costs are often unknown or ignored [33].

The potential delays and additional associated costs relating to labour productivity can come from increased danger to staff, slower productivity (due to need to protect the product, wearing additional clothing, needing additional breaks etc), or enforced stoppages [32].

Weather and Weather Types

There are numerous types of weather and several subdivisions within these types, however for expediency it is important to keep the discussion to relevant parameters, this is discussed further in this chapter below.

The Met Office [34] has listed out 13 weather types, however some of these overlap, In Table 1 below the list on their website covers, Clouds, Snow, Thunder and Lightning, Frost and Ice, Rain, Fog, Humidity, Hail, Hurricanes, Wind, Tornadoes, Storms and Heat. As the purpose of this research is to examine the impact that weather types have on productivity some of these listed above can be immediately eliminated or grouped.

In summary the weather systems that will be considered within the research but will provide a total stop to work and therefore are not considered in the survey will be - Thunder/lightning/ storms/ hurricanes and tornadoes.

Table 1. Weather Types

Weather types	Potential impact	Levels of Impact
Clouds	Overcast sky, and of itself is not expected to have any impact on productivity	Not included
Snow	Can affect productivity by enforcing stoppage to work, or reducing visibility	Incorporated in Light Rain
Thunder and Lighting	As a standalone weather element will have minimal impact on productivity (it is the rain fall that often accompanies a storm that will impact). Although Cranes are unable to operate in an electrical storm	Not included
Frost and Ice (extreme Cold)	This will enforce stoppages in some instances, will require more protection of product in some cases and could increase hazards, especially when working at height. Also, cold can have an emotional impact on Labour and typically will require greater, productivity reducing, protective clothing	Extreme cold is taken as ≤ 0°C. Material impact is different to this and so this focus is purely on impact on Labour output.
Rain	This can be split into heavy and light rain, both can impede visibility, heavy rain may enforce stoppages, both can create greater hazards especially at height, and will typically have an emotional impact and require greater, productivity reducing, protective clothing	Light Rain is given as a measurement of over 6 mm but less than 19 mm in any 24-hour period. This assumes a steady light rain for a number of hours [35]
		Heavy Rain is given as over 19 mm in 24-hour period on the same principles as above [35]
Fog	Fog is similar to Light rain in that will reduce visibility and possibly require greater levels of protective clothing.	Included in the above Light rain
Humidity	Humidity when combined with high temperatures can impact the levels of fatigue.	As Humidity is combined with Heat as an impact, and has less impact in cooler weather, it has been included with Heat below
Hail	Hail is frozen rain, but unlike rainstorms often hailstorms are very short lived. Due to the nature of Hail external work is typically temporarily halted during a rainstorm for reasons of worker safety, and while this can slow productivity, the potential for Hailstorms in the UK is decreasing as is their intensity [36].	Not included
Hurricanes/ Storms/ Tornadoes	Typically, these will enforce a stoppage rather than reduce productivity	Not included
Wind	Wind will increase hazards particularly when working at height and may require protection work in progress. It can also impact on the ability of cranes to life and may have an impact on the emotional state of workers.	15MPH taken as wind speeds of between 13 and 18 MPH can have a detrimental effect, and over 23 MPH can stop work. [37]
Heat	Excessive heat may lead to extra protective processes on products, it can impact the emotional state of workers, will lead to the need for more breaks, and in extreme circumstances may lead to altered work patterns.	Excessive heat is listed at different levels across the UK and can be adjusted as earth's temperature rises. For this research 25°C was used as the time of writing lowest of UK extreme temperature limits [38]

The weather systems that will be considered for the research and will be part of the survey due to it having a percentage impact rather than a complete stop, will be - Cold, heat, light rain/ fog, heavy rain/Snow, humidity and wind.

Research Methodology

This paper used a literature search to establish context for the work from existing published works, gaps in the knowledge were then discussed using data analysis and questionnaires. The questionnaires required knowledge of the productivity of a variety of labour on construction sites, to this end academics who train the future manual workforce were approached for their responses. Some Further Education Colleges based in North Wales, Northwest UK, Midlands and East Midlands were all approached to gather responses, and further responses were generated using the Construction Industry Training Board network.

The questionnaire was developed to establish the rate at which productivity may drop (or improve) with the variety of weather types listed above. The respondents were not told that the ultimate goal was to establish costs on modular build, as this may have skewed the data, if for example one of the respondents was not pleased with the prospect of modular construction as a development. Especially as some of the manual trades they are trained in may become more scarce if modular production grows. And it was deemed unnecessary to inform them of the end goal to establish the impact of weather. The Questionnaire was distributed via JISC online surveys, a link was sent to all college contacts and distributed to staff from there. There were 28 responses to the questionnaire and the results are analysed in the discussion below.

Discussion

Construction Activities

There are many different activities that take place in the traditional production of any building project, and as such for ease, efficiency and utility it was important to categorise these activities. For this research it was decided to use the category as set out in the NRM2 [39]. Those activities that are carried out as part of the factory based, environment controlled, modular production will have the impact of weather eliminated, whereas those that remain will still be subject to weather impact, therefore the list of activities is further categorised in this. Once the activities have been established the impact of weather on each activity can be developed, each activity will be impacted in several ways and the model will seek to address the impact by analysing the probability of impact depending on location in the country (UK only).

This paper will focus on the impact of weather on labour productivity, although there is a further impact of materials impact and equipment impact, this is discussed briefly below [1].

Impact on Workforce

Assessing the impact on the workforce is complicated by the nature of the range of human tolerance to a variety of weather types. Some workers will cope with lower temperatures more readily than others, and some will cope with higher temperatures than others etc. it is therefore important to set some assumed parameters to enable an analysis of the topic in a systematic way. Productivity is generally impacted in a variety of ways for example physical impact such as fatigue or restrictive clothing; activity impact for example by having to protect the product from the weather; and emotional impact for example where cold weather may make workers feel less inclined to work. Some of the assumed impacts are set out below by weather type [32].

Weather Analysis

The met office produces daily records of weather across the UK [40] and in analysing this data it is possible to calculate a probability for each weather type listed above. The process used in this research paper involved a tally of each day over a 5-year period (from September 2017 to August 2022). This covers temperature ranges, wind speed and is presented at 2 times of day, for the analysis midday data was used. The rain measurement was shown on a different chart and was assessed against the criteria set out above, that of 5 mm and under is negligible, 6 mm to 18 mm is considered significant light rain and 19 mm and above is considered heavy rain.

There are 35 weather stations across the United Kingdom, and all have been used in this research paper. The Process of data collection involved the manual tallying of each aspect of the records listed above that went above or below the accepted range, for example if a daily temperature record was over 25°C then a tally was taken for that day in that location. These tallies were then collated seasonally using the meteorologic seasonal split of December, January and February (Winter), March, April, and May (Spring), June, July and August (Summer), and September, October and November (Autumn) [34]. Finally, the average for each station for each season was calculated over the 5 years. Consideration was given to using more years to provide a more accurate analysis, however due to the impact of recent climate change, 5 years was deemed the most accurate.

The probability distribution would seem logical for some as can be seen in the Figures 1-5 below, for example there is a greater chance of high temperature in summer months and in southern counties, but for others there is an

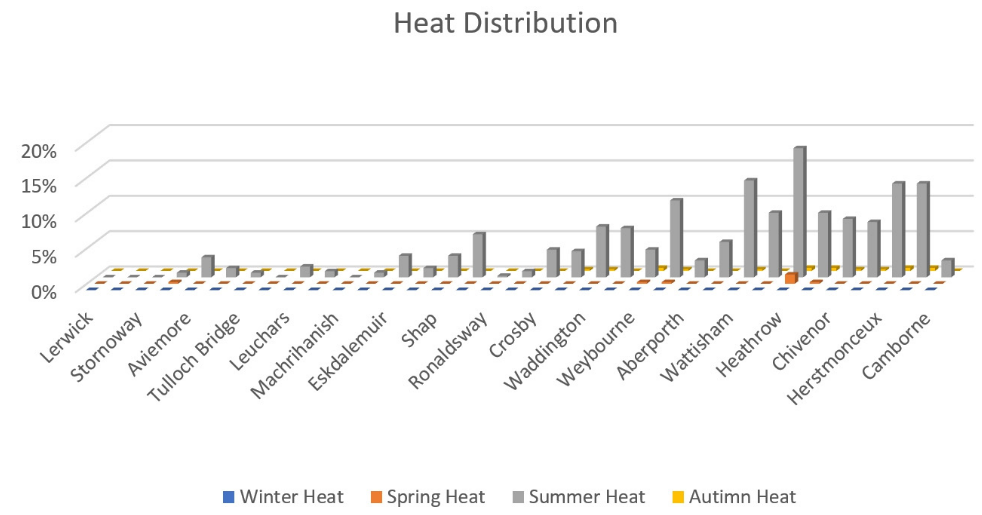

Figure 1. Seasonal Heat distribution.

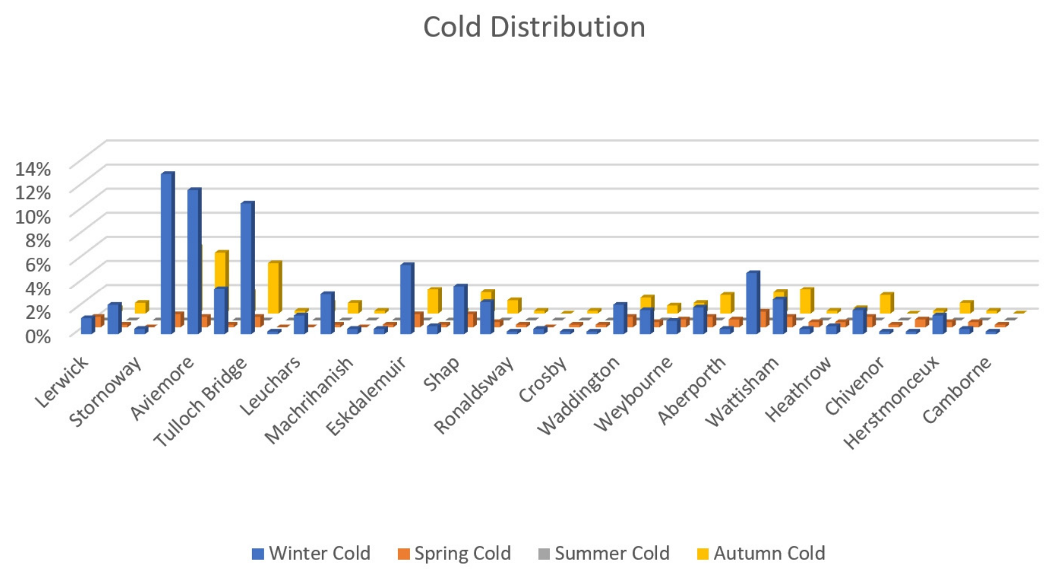

Figure 2. Seasonal Cold Distribution.

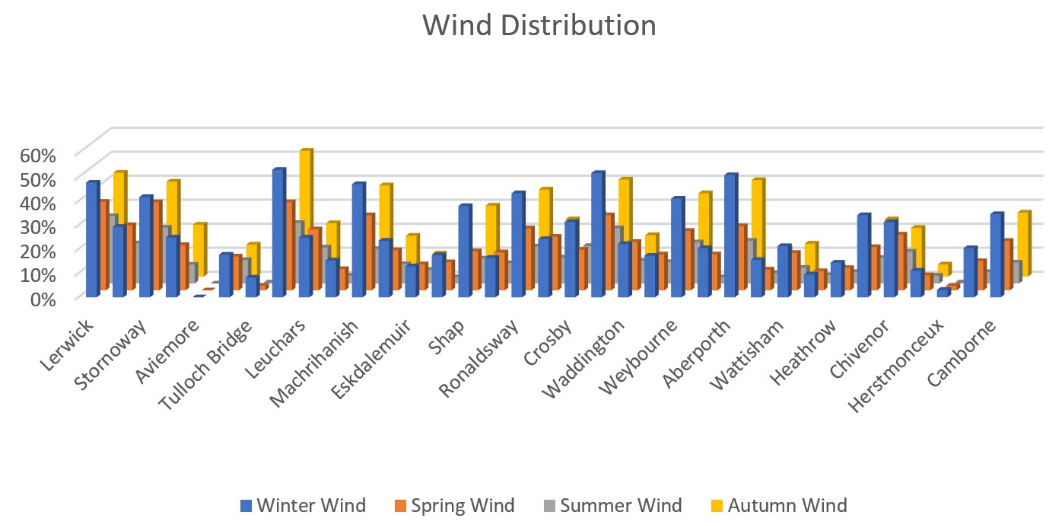

Figure 3. Wind distribution.

even distribution, and some stations had anomalies that may be accounted for by local topography, for example the lack of high winds recorded at Aviemore station.

The Figure 6 below shows a summary of the probabilities for each season and for each location. It is important to realise that while these locations are reasonably well spread, due to topography and built environment influences the site location may not have the same weather impact as the closest weather station, however this was deemed a potentially small change to the probability which is not an exact science anyway. Therefore, any variance due to this was ignored.

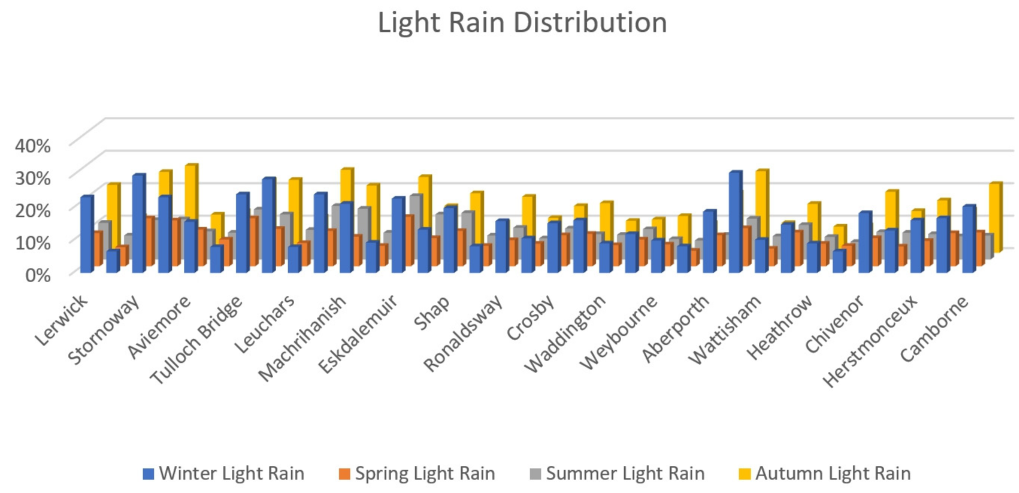

Figure 4. Light Rain distribution.

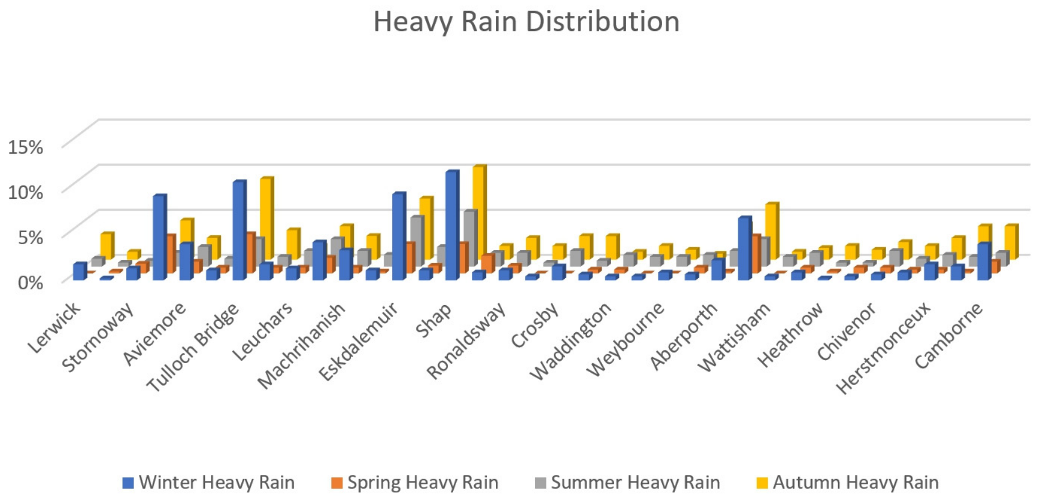

Figure 5. Heavy Rain Distribution.

Probability of weather type as a percentage																				
	Winter					Spring					Summer					Autumn				
	Heat	Cold	Wind	Light Rain	Heavy Rain	Heat	Cold	Wind	Light Rain	Heavy Rain	Heat	Cold	Wind	Light Rain	Heavy Rain	Heat	Cold	Wind	Light Rain	Heavy Rain
Lerwick	0	1	48	23	2	0	1	37	10	0	0	0	28	11	1	0	0	43	21	3
Wick	0	2	29	7	0	0	0	27	6	0	0	0	17	7	0	0	1	29	11	1
Stornoway	0	0	42	30	1	0	0	37	15	1	0	0	23	12	1	0	0	40	25	2
Loch Glascarnoch	0	13	25	23	9	0	1	19	14	4	1	0	8	12	2	0	6	22	27	4
Aviemore	0	12	0	16	4	0	1	0	11	1	3	0	0	9	2	0	5	0	12	2
Dyce	0	4	18	8	1	0	0	14	8	1	1	0	10	8	1	0	2	13	13	2
Tulloch Bridge	0	11	8	24	11	0	1	2	15	4	1	0	0	15	3	0	4	4	23	9
Tiree	0	0	53	29	2	0	0	37	12	1	0	0	25	14	1	0	0	52	22	3
Leuchars	0	2	25	8	1	0	0	25	7	1	2	0	15	9	2	0	1	22	11	2
Bishopton	0	3	15	24	4	0	0	9	11	2	1	0	3	17	3	0	1	7	26	4

Figure 6. Probability of weather occurrences by Season and weather station location.

	Probability of weather type as a percentage																			
	Winter					Spring					Summer					Autumn				
	Heat	Cold	Wind	Light Rain	Heavy Rain	Heat	Cold	Wind	Light Rain	Heavy Rain	Heat	Cold	Wind	Light Rain	Heavy Rain	Heat	Cold	Wind	Light Rain	Heavy Rain
Machrihanish	0	0	47	21	3	0	0	31	9	1	0	0	14	16	2	0	0	38	21	3
Boulmer	0	0	24	9	1	0	0	17	6	0	1	0	8	8	1	0	0	17	10	1
Eskdalemuir	0	6	13	23	10	0	1	11	15	3	3	0	6	20	5	0	2	10	23	7
Aldergrove	0	1	18	13	1	0	0	12	9	1	1	0	3	14	2	0	0	9	14	1
Shap	0	4	38	20	12	0	1	16	11	3	3	0	10	14	6	0	2	30	18	10
Leeming	0	3	16	8	1	0	0	16	6	2	6	0	8	7	2	0	1	11	9	2
Ronaldsway	0	0	43	16	1	0	0	26	8	1	0	0	15	10	2	0	0	36	17	2
Bridlington	0	0	24	11	0	0	0	22	7	0	1	0	11	7	0	0	0	24	11	2
Crosby	0	0	31	15	2	0	0	17	10	0	4	0	16	10	2	0	0	26	14	3
Valley	0	0	52	16	1	0	0	31	10	0	4	0	23	8	1	0	0	40	15	3
Waddington	0	2	22	9	0	0	1	20	7	0	7	0	10	8	1	0	1	17	10	1
Shawbury	0	2	17	12	0	0	0	15	8	0	7	0	9	9	1	0	1	11	10	2
Weybourne	0	1	41	10	1	0	1	25	7	0	4	0	17	6	1	0	1	35	11	1
Bedford	0	2	20	8	1	0	1	15	5	1	11	0	3	6	1	0	2	10	9	1
Aberporth	0	0	51	19	2	0	1	27	10	0	2	0	18	8	2	0	0	40	19	4
Sennybridge	0	5	16	31	7	0	1	9	12	4	5	0	4	13	3	0	2	12	25	6
Wattisham	0	3	21	10	0	0	1	16	5	0	14	0	7	7	1	0	2	14	9	1
Almondsbury	0	0	10	15	1	0	0	8	10	1	9	0	3	11	2	0	0	4	15	1
Heathrow	0	1	14	9	0	1	0	9	7	0	18	0	5	7	0	0	0	8	8	2
Manston	0	2	34	7	0	0	1	18	6	1	9	0	11	5	0	0	2	24	8	1
Chivenor	0	0	31	18	1	0	0	23	9	1	8	0	13	8	2	0	0	20	19	2
Exeter	0	0	11	13	1	0	1	6	6	0	8	0	3	8	1	0	0	5	13	2
Herstmonceux	0	2	3	16	2	0	0	2	8	0	13	0	0	8	1	0	1	1	16	2
Hurn	0	0	20	17	2	0	0	12	10	0	13	0	5	7	1	0	0	10	13	4
Camborne	0	0	35	20	4	0	0	21	10	1	2	0	9	7	2	0	0	27	21	4

Figure 6. Probability of weather occurrences by Season and weather station location (Continue).

Productivity

Once we have the probability of a particular weather type in a particular location, the next step is to assess the impact of that weather type on productivity. The pilot study questionnaire was carried out to analyse the questions to be asked and from this data parameters were set for each of the weather type's impact. Typical responses were quantitative in nature although there was an opportunity for qualitative feedback holistically on the topic. An analysis of responses shows a suggested decrease in productivity when particular examples of weather types happen while particular activities take place. This pilot study results were then used to provide assumed reduction in productivity, and this was used to develop potential cost reductions on modular built projects.

From the pilot study the reduction for weather relating to Brickwork are seen in the Table 2 below. Two consecutive pilot studies were developed, in the first one where 18 responses were achieved had banding up to 10% +, There were a few responses that stated this top category, and so when the second pilot study was developed some had a higher banding category. On the second pilot study only 15 valid responses were received. The next stage of this research is to use semi structured interviews and focus groups using the Delphi method of data collection, as this is deemed to provide a more accurate response, however for the benefit of this paper a combination of both pilot studies will be used, and where a respondent has selected 10% + in the original studenty it has been taken as the next category up in the second category.

The results from the surveys were then averaged out to provide the data Table 2 below, where there is a misunderstanding of the question then this has been discounted, removing outliers. For example, one respondent put 100% reduction in productivity on Carpentry activities with light rain but only 10% for heavy rain, this was deemed a mistake and removed.

Table 2. Averaged response from pilot study

	Heat	Light Rain	Heavy Rain	Wind	Cold
Masonry	7%	62%	81%	5%	62%
Carpentry	8%	11%	16%	8%	12%
Decoration	8%	17%	41%	10%	57%
Window and door installation	8%	4%	100%	100%	6%
BWIC	6%	12%	12%	7%	8%
Plumbing/Mechanical	9%	5%	8%	10%	5%
Joinery	6%	7%	6%	2%	9%
Concrete work in situ	5%	10%	64%	9%	43%
Electrical work	10%	15%	5%	0%	15%
Above ground drainage	12%	0%	25%	10%	20%
The following items had no response within the pilot study and so assumptions have been made based on similarity to items above. For example, the impact on internal partitioning could be assumed to be similar to internal joinery etc.					
Internal Partitioning	6%	7%	6%	2%	9%
Plaster boarding and Skim	8%	10%	10%	10%	9%
Floor Finishes	0%	5%	15%	10%	9%

Cost Implications

The intention of the cost model developed here is to allow stakeholders to assess the impact of weather on activities that would be replaced with the use of modular construction. To do these assumptions were made on the level of modular use (see Table 3 below).

The cost model will need to combine the probability with the possible productivity reduction in order to achieve the potential impact on the cost. While this appears to be a basic input the probability aspect is further complicated with the differing impact based on the time of year each activity takes place. Therefore, the start of the project with the duration is needed to assess when each of the activities takes place − this will give a probability for each weather type, for the individual project. Greater accuracy can be achieved by breaking the project into more parts rather than the thirds proposed, however as the model uses probabilities there is a certain amount of variation built into the calculation and so the impact of this greater accuracy is minimal compared to the increased complexity of

Table 3. Table of Assumptions

Assumptions used to enable adequate calculation of cost impact	
Modular construction will include inner walls, internal skin of external walls, Insulation, windows, doors, floors ceilings, plaster boarding, skim, first and second fix joinery, electrical and mechanical works, and internal finishes and decoration.	Items not included include, external skin of external wall, roof structure and cladding, sub structure, connection of services etc.
Assumption made that presenting the data in seasons will not overly impact on the levels of accuracy	Assumption made that presenting the data with activities in the closest third of build where they will be used will not overly impact on the accuracy of the data
Assumed that pilot study responses were sufficient to develop the cost model, greater accuracy could be established with a more in-depth study, but for the purposes of establishing the principle of the cost model the study is deemed sufficient	Assumed that the closest weather station to the project will accurately reflect the weather at the construction site, influences of differing topography and built environment are ignored
It is possible to have high winds and heat on the same day and this might have more impact, but it is not possible to gather this data from the data sets used, and the potential combination of weather types would exponentially increase the potential impacts making it too cumbersome for a useful model. Therefore, it is assumed they work independently of each other	

the calculation.

$$M^1 = Pr^1 \text{ x } P^1$$

P^1= Probability (probability of weather occurrence in given month, presented seasonally, and set against the activity occurring in that month)

Pr^1 = productivity impact

M^1 – Impact on cost of Masonry activity

Using the formulae above it is possible to assess the potential impact on cost for each of the activities that will be replaced with the use of modular, this is a cost reduction o the price of using modular as opposed to traditional techniques and will therefore enable a more accurate cost comparison of production types.

Activity Cost Analysis

As discussed above the activities that can be replaced in a traditional production can range from a minimal amount to a complete replacement, therefore an assumption needed to be made to aid in the development of a cost model that can be used. For this example, the activities revolve around structural aspects pf the build but excluding a core construction (service shaft, lift shaft and stairs etc), excluding external wall and roof cladding and excluding foundations, but including all internal finishes. The list can be seen in Table 4 above along with the formula for the calculation of cost reduction and the location within the timeline of production. The activity name is also meant as

Table 4. Activities to be replaced by modules

Activity to be replaced by Module	*Formulae for cost adjustment*	*Portion of the project allocated to the activity*
Masonry	$M^1 = Pr^1 x P^1$	*First Third*
In-Situ Concrete	$C^1 = Pr^1 x P^1$	*First Third*
Carpentry First Fix	$CF^1 = Pr^1 x P^1$	*Second Third*
Joinery Second Fix	$JS^1 = Pr^1 x P^1$	*Final Third*
Window and external door installation	$W^1 = Pr^1 x P^1$	*First Third*
Internal Partitioning	$PT^1 = Pr^1 x P^1$	*Second Third*
Plaster boarding/Skimming	$PB^1 = Pr^1 x P^1$	*Second Third*
Plumbing/Mechanical	$M^1 = Pr^1 x P^1$	*Second Third*
Electrical Installation	$E^1 = Pr^1 x P^1$	*Second Third*
Decoration/Finishes	$D^1 = Pr^1 x P^1$	*Final Third*
Builders Work in Connection	$BW^1 = Pr^1 x P^1$	*Second Third*
Above Ground internal drainage	$DR^1 = Pr^1 x P^1$	*Final Third*
Floor Finishes	$F^1 = Pr^1 x P^1$	*Final Third*

a label, rather than an intention of actual coverage. For example, the masonry label intended to cover the internal skin of a cavity wall and not the external cladding (although both could be covered by the term masonry).

Once this is allocated and the length and start date of the project is known it is possible to allocate impact of weather by season on each activity. For example, if a build project is 12 months long and starting in March, then Masonry, Concrete and window fitting will be impacted over 4 months (March, April, May and June) or all of Spring and a third of summer impact. Therefore, the impact will be weighted against the impact of that season it falls in, in this example 75% Spring impact and 25% Summer impact (3 months Spring, 1 Month Summer).

The cost will be project specific and it is assumed the stakeholder will have this data to input, however, to show an example of how this may work in industry and to express the impact of weather on this please see the example of a build taken form Spons 2019 Price book. [41] on Page 119 there is a cost model for a palliative care build including offices, is based on a single three storey traditionally built building. The model location is Greater London making Heathrow the closest weather station.

Assumptions for the Example Cost Model Calculation

It has been assumed that the start of the project will be December the first, as we have no indication of when this actual build started, the start of the Winter season was chosen for ease. It is also going to be assumed the build time for the project is 24 Month period. Therefore, each of the thirds of the build will span the following seasons.

- First third – 8 Months from December to July Inclusive that is 100% Winter Season, 100% of Spring and 66% of Summer.
- Second Third – 8 Months from August to March Inclusive which equates to 33% Summer, 100% Autumn, 100% Winter and 33% Spring

- Final Third – 8 Months from April to November Inclusive – 66% Spring, 100% Summer and 100% Autumn.

Using the build model in Central London [41] as the example we can carry out the following calculation to assess the weather impact.

Example Cost Model Input

As an example of how this cost model would work, the Central London Palliative care cost model [41] was used and each activity can be seen in the Table 5 below. The allocated cost per M2 for the masonry element on this build is £190 per M2, but this would include facing brickwork and fixing cavity ties, both of which activities would not be replaced by the use of Modular based on our assumptions stated above. The adjustments for these came from the same source [41] and included. Facing brick installation including the cost of the bricks = £34.52 (Page 257) and the cost for forming the cavity and fixing the ties would be 0.77 (Page 311).

As the work shown above is based on labour productivity there is a need to establish what the labour rate for the work is, as the closest example the labour element of blockwork installation (Page 302) is set at 31%. A similar process was used for all of the cost activities shown in Table 5 below.

Table 5. Activity based cost adjustments

Element	Overall cost	Labour percentage	Total labour rate	Notes
Masonry	£155.00	31%	£48.00	
Carpentry GIFA	£300.00	57%	£171.00	Between pages 331 and 337
Decoration	£15	74%	£11	Page 515
Windows	£500 (average taken)	24% (aluminium windows)	120	Page 441 averaging outdoors and windows aluminium
Builders Work in Connection (BWIC)	32.89	100%	32.89	Page 638 (majority of work is Labour only activities
Plumbing	300/m^2 GIFA	47%	£141	Given as Gross Internal Floor Area (GIFA)
Joinery cost	Avg £600 per doors set	12%	£72	No joinery breakdown on model except for door sets
Concrete	N/A on model,	29% (avg)	Avg – £28.83	Cost taken off alternate job for comparison. Floor cost is £17 per M2 for labour
Internal Partitioning	65 and 90/M2 avg	58%	£44.95	Spons page 398 as an example
Plaster boarding and Skim	£16	50%	£8	Page 399 and 512 onwards. Skim is 98% plaster board is 43%. Average of 50% used as majority of labour element on cost model is Plaster boarding
Floor Finishes	£34 avg	30%	£10,20	page 512 onwards
Electrical installation	280/M2 GIFA	57%	£160 GIFA	Based on Gross internal floor area (GIFA)
Above Ground Drainage	The majority of cost in this item is for RWG, but as this would not be a part of the module package is ignored. the internal foul drainage systems are assumed to be included in the plumbing cost as they are not separated out in the cost model and so has been ignored.			

Once all of the data is available as above, the cost model can be developed, there are several ways in which this can be presented as the variables are weather impact, location, activity and time of year.

For example, it can be said in Heathrow in Spring, there is a 7% chance of a 60% reduction in brickwork cost (£155 per M2) in other words in Spring there is a 7% chance the brickwork will cost and extra £93per M2 (see breakdown in Table 6 below).

Following this see the example cost impact calculation for the Blockwork element in Table 7 Below.

Table 6. Averaged results from pilot study

	Heat	Light Rain	Heavy Rain	Wind	Cold
Masonry	7%	62%	81%	5%	62%
Carpentry	8%	11%	16%	8%	12%
Decoration	8%	17%	41%	10%	57%
Window and door installation	8%	4%	100%	100%	6%
BWIC	6%	12%	12%	7%	8%
Plumbing/Mechanical	9%	5%	8%	10%	5%
Joinery	6%	7%	6%	2%	9%
Concrete work in situ	5%	10%	64%	9%	43%
Electrical work	10%	15%	5%	0%	15%
Above ground drainage	12%	0%	25%	10%	20%
The following items had no response within the pilot study and so assumptions have been made based on similarity to items above. For example, the impact on internal partitioning could be assumed to be similar to internal joinery etc.					
Internal Partitioning	6%	7%	6%	2%	9%
Plaster boarding and Skim	8%	10%	10%	10%	9%
Floor Finishes	0%	5%	15%	10%	9%

Blockwork and Inner Wall

Table 7. Example cost adjustment calculation (Masonry)

Note – the calculation of impact is based on the percentage of impact averaged out following the pilot studies as seen in Table 6 multiplied by the cost of labour for that element of work as seen in Table 4

Brickwork £48 Labour on Example	Work allocated	Heat Impact 7% = £3.36	Light Rain 62% = £29.76	Heavy Rain 81% = £38,88	Cold 62% = £29.76	Wind 5% = £2.40
Winter	100%	0% = 0%	9% = 9%	0% = 0%	1% = 1%	14% = 14%
Spring	100%	1% = 1%	7% = 7%	0% = 0%	0%= 0%	9% = 9%
Summer	66%	18% = 12%	7% = 5%	0% = 0%	0%= 0%	5% = 3%
Autumn	0%					
Totals		Average of 5% (avg 2 and 2/3rds) £3.36 = £0.17	Average of 18% x £29.76 = £5.36	Average of 0% of £38.88= £0.00	Average of 0% of £29.76 = £0.00	Average of 10% of £2.40 = £0.24
Total	£5.77 impact on this project per M2	Or 12% (5.77 / 48) increase on Labour Costs of Masonry due to All Weather types	Or 4% (5.77 / 155) increase on overall cost of Masonry due to All Weather types			

The process shown in Table 7 is to apply the probability of each weather type hitting in each season taken from application of Figure 6 above. This is then weighted impact by the proportion of the activity carried out in that season, which is the averaged out. For example, with Heat above, there is a probability of 0% impact for heat in Winter, and a 1% impact of probability of heat in Spring, and 18% in Summer (but as only 2/3rd of the work is summer this is brought down to 12%). This is then averaged as an impact 13% divided by 2 2/3rd gives a potential impact of 5% for heat. The labour rate for Masonry taken from Table 6 is £48 for this example, with a potential heat impact of 7% this gives a potential heat cost of £3.36 (7% of £48). With a 5% probability changing this to a potential impact of £0.17 (5% of £3.36). when taking all of the potential weather impacts individually (it is assumed that each weather type acts independently for this model) it gives a potential £5.77 cost impact. Which is 12% increase on labour costs (5.77/48) or 4% impact on masonry cost (5.77/155).

This process was then completed for all other activities and results can be seen in the Table 8 below.

Table 8. Summary of example cost adjustment calculation

	Addition to labour cost	Addition to element item	Equates to	Impact on example cost model
Blockwork Inner wall skin	12%	4%	5.77/M2	4270
In situ Concrete	3%	1%	0.84 / M3	420
Windows and doors	11%	3%	13.34/m^2	1733
Carpentry	1%	1%	2.19/m^2 GIFA	3158
Plumbing	2%	1%	2.32/m^2 GIFa	3215
BWIC	2%	2%	0.60/m^2 GIFA	865
Partitioning	1%	1%	0.46/M2	842
Plaster boarding	2%	1%	0.15/M2	419
Electrical Installation	2%	1%	2.72/m^2 GIFA	3992
Decoration	3%	2%	0.34 / M2	949
Joinery	1%	0%	0.84/m^2 GIFA	1211
Flooring	1%	1%	0.13/m^2	178
Total saving by using modular due to weather				21,252
Cost model cost				£3,451,000
Percentage saving				0.6%

CONCLUSIONS

Weather can have a detrimental impact on productivity, and thereby impacting costs. One solution being offered in this paper is to remove many of the onsite activities and replace them with modular production techniques. As these modules are produced in factory units under very controlled conditions, they are not therefore subject to the potential losses that can occur if using traditional techniques. The focus of this paper was on labour productivity and the impact a variety of weather conditions from across the United Kingdom will have on this productivity and then ultimately the cost. The basic premise was to establish which activities in a traditionally built project would be replaced by a modular build, and the focus of the weather impact was on these activities. Modular construction can range in impact from singular rooms (such as bathroom pods) up to entire fabric and structure. For the purposes of this cost model only typical activities were used and were restricted to some structural elements and internal finishes and services.

Ultimately the potential impact will vary depending on where the project is built, when the project is started and how long the project will last for. An example cost impact was carried out on a model provided [41] and showed a potential cost impact of 0.6%. While this appears fairly insignificant, when taken in the context of this only being one of many cost variables used and that the current average profit margin in the UK is approximately 4% [42], a potential increase of 0.6% is more important. This would also need to be set against the potential that modular build itself is more expensive, and also assumes that any costs associated to weather during installation are included in the cost of the module.

While this paper has not in itself made the case for modular it has shown that some of the cost variables that are not currently taken into account when doing a cost comparison between Traditional and Modular production, are not insignificant and justifies more careful consideration in the future.

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