KILOMETER COUNTER FOR CONSTRUCTION: KxK PROPOSAL FOR AN INDICATOR OF SUSTAINABILITY

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Summary

In the developed world, the number of products now used in building construction projects is much higher than in the past, and the distances that products are transported to reach building sites are much greater. This can be deduced from delivery notes for supplies arriving at building sites every day. In 2010, the LiTA research group carried out a preliminary detailed study of this issue, with regard to a building type for a fast food chain of restaurants built around the region of Catalonia. The results of the study led to the proposal of a numerical indicator called KxK. This indicator is calculated by multiplying the number of kilogrammes of each product used in the construction of the building type by the kilometres that the product is transported from its point of supply to the building site.

Keywords: transport, construction products, parameters of sustainability

1 Introduction and objectives

In recent years, the unit costs of transport have dropped and legal barriers that hindered the movement of goods have been removed. Consequently, many products of distant origin have become cheaper and more attractive than local products, despite the effort, time and energy invested in their transport. The added advantage of using construction products of distant origin is that the environmental impact of manufacturing the products is obscured and moved to other far-off regions.

Some highly standardized construction products that are mass produced and consumed, such as steel and concrete, have become highly interchangeable in the market and are transported around the world without any label of origin. At the other extreme are a very few products that have taken on a "made in..." designation of origin. These are exported worldwide from their recognized point of origin, as there are no comparable local products anywhere else.

When architects draw up plans, they must specify the characteristics of the products that will be used. However, they do not normally indicate the geographic origin of these products. Over time, architects have become ignorant of the geographic origins of the products specified in their designs. The final decision about product origin is often in the hands of the construction company's purchasing managers, who focus on price and delivery time only.

Prior to the industrial revolution, architects had to ensure that they indicated the geographic origin of the construction products to be used in their designs, as this was a society of small-scale manufacturing, in which products were not highly elaborated and means of transport were extremely limited.

Raw materials for construction products are not evenly distributed over the world. Consequently, vernacular architecture has always reflected the local availability of materials and local builders' knowledge of their use. Now, most architects receive international training and construction products are considered universally available, due to fast, easy and affordable transport.

2 Method

First, we selected a building type for this study that was neither a common apartment building nor a unique structure. We chose a building design for a chain of businesses. The design was to be built throughout the region almost as a series, with a few adaptations to local circumstances. The secondary aim of choosing this kind of building was to offer the study results to the property developer, so that actions could be implemented to reduce or limit the impact of transporting construction products, if necessary. As the building type would be constructed on numerous occasions, it would be worth making the effort to optimize some of the decisions, such as the origin of the construction product supply.

Fig. 1 *Exterior views of the building type under study*

Second, we contacted the directors of a restaurant chain that currently has 35 buildings of approximately 500 m^2 each (http://www.viena.es/establiments/). The company agreed to participate in the study and provided documents corresponding to real invoices for the products supplied to construct one specific building. All the documents on the products delivered to the building site state the weight and origin of the transported goods. The restaurant chain already supplies food products for all its establishments from a central logistics centre. Therefore, it already considers the impact of transporting food products on time and costs. However, the construction of the company's buildings is not yet evaluated in this way.

Fig. 2 *On the left, a ground plan for the type of building under study; on the right, a photograph of an interior of this building type*

Third, we identified the main construction products to consider in the study. The real number of products used to construct a building is much higher than the number selected here. We excluded any products that were supplied in very small quantities. Consequently, a total of 45 construction products were indexed. Some of the items listed in Table 1 combine several forms of the product for simplicity, for example, powder, panel and paste. The trade names are written in inverted commas.

Tab. 1 *The forty-five construction products indexed in the study*

Product	Product	Product
HM20 mass concrete	Ceramic tile	Pine wood
HA25 reinforced concrete	Fine brick	Solid iroko wood
Acer B-500-S	Porcelain floor tile	Oak wood
PVC	Butyl rubber membrane	Medium-density fibreboard (MDF)
Aluminium	Others	Copper
Stainless steel	Sliding doors/windows	Polycarbonate
S-275-JR steel	M80 cement mortar	Zamak
“Delta Drain SM” membrane	Glass	Polyethylene
Geotextile sheet	Granite	Sanitary ware
Lumber	Cement-based adhesive	Galvanized steel
Waterproof sheet	Ceramic	One-coat plastering mortar
Plaster	Marble	Emulsion paint
Extruded polystyrene	Plasterboard	“Oxiron” paint
Spruce wood	Mineral fibre	Waterproof paint
“Onduline” bituminous sheet	Fire retardant paint	Gloss paint

Fourth, we identified the geographic origin of each product. Immediately, we established that it was very difficult to document in detail the entire path of a construction product from the extraction of the raw materials to final delivery at the building site. These is because construction products pass from company to company, cross different regions, are transported in different ways and undergo changes in bulk as they are made smaller by technical processes of transformation. Therefore, we decided to focus on the last transport stage only: from the last manufacturing plant to the construction site. We indexed 39 different origins. On a map, these would form a large compass rose with the building site at the centre.

Tab. 2 *List of suppliers of the construction products indexed in the study*

Company	**Geographic origin**
Promsa	Mataró (Barcelona)
Ferrallas Garmun, S.L.U	Les Franqueses del Vallès (Barcelona)
Ferroplast	Muras (Granada)
Cainox & Blücher	Badalona (Barcelona)
Asfaltex, S.A	Sant Cugat del Vallès (Barcelona)
Topox	Vallmoll (Tarragona)
Onduline	Gallarta (Vizcaya)
Terreal Terracota	La Pobla de Vallbona (Valencia)
Saint Gobain Weber Cemarksa	Montcada i Reixac (Barcelona)
IC Brancós, S.A	La Bisbal (Girona)
Sika, S.A.U	Alcobendas (Madrid)
Teuleria Almenar, S.A Tealsa	Almenar (Lleida)
Hormicemex, S.A	Sant Feliu de Llobregat (Barcelona)
Rockwool Peninsular. S.A.U	Caparroso (Navarra)
Compac, The Surfaces Company	Sant Fruitós del Bages (Barcelona)
Knauf	Guixers (Lleida)
Knauf	Rottleberode (Germany)
Knauf	Iphofen (Germany)
Knauf Insulation	Lannemezan (France)
Knauf	Gruaro, Verona (Italy)
Instalaciones de Cristaleria y Ebanisteria, S.L	Sant Quirze del Vallès (Barcelona)
Metalisteria y Seralleria Ortiz y Cano, S.L	Sabadell (Barcelona)
Global Inox, S.L.U	Cervelló (Barcelona)
Unex Aparellaje Eléctrico S.L	Martorell (Barcelona)
Iguzzini Iluminazione Spa	Recanati (Italy)
Simon, S.A	Riudellots (Girona)
Plieco España, S.A	Estivella (València)
Isofoton	Málaga (Andalucía)
Roca Sanitarios, S.A	Sabadell (Barcelona)
Mediclínics, S.A	Santa Perpètua de Mogoda (Barcelona)
Sangrá	Martorelles (Barcelona)
Morgui Clima S.L	Badalona (Barcelona)
Cromotech	Bérgamo (Italy)
Xylazel, S.A	Porriño (Pontevedra)
Sika, S.A.U	Alcobendas (Madrid)
Instalaciones Decora, S.L	Sabadell (Barcelona)
Vidres Barberá, S.L	Barberà del Vallès (Barcelona)
Vives Azulejos y Gres, S.A	Alcora (Castelló de la Plana)
Draka, S.L	Santa Perpètua de Mogoda (Barcelona)

Fifth, we had to quantify the impact of transport using one parameter and one unit. One option was to present the results of this impact as MJ or t of CO_2. However, we decided to use a more concise and recognizable form, based on parameters commonly used by architects. As a result, we proposed the new parameter KxK:

$$KxK = Sum\ (Kl_{i,}\ \text{no. of kilometres transported} \times Kg_{i,}\ \text{no. of kilogrammes transported})$$

Sixth, as in any preliminary study, we decided which variables could be simplified and which excluded. The following factors were considered:

- Products that are not very dense, such as thermal insulation materials, were excluded. These products are transported long distances, even though their weight (in kg) is low.
- Small products of high added value, such as taps, were excluded. These products are transported in small vehicles along with other products and distributed to different building sites consecutively.
- Lorries almost always return empty from building sites. This second journey with no load was not taken into account.
- The real distribution of products is not always from the factory directly to the building site, as secondary warehouses are often used to break up the load.
- The use of some products, such as water, is not quantified directly in kilogrammes at the construction site, but as a financial cost that is part of a complex bill. In addition, only part of the water is incorporated in the mass of the building, whilst the rest is used in ancillary processes. Water is supplied to the building site via the public network, which often mixes water from local and distant sources. Water is almost always transported in pipes; it is hardly ever carried in transport vehicles.
- Transport vehicles are also heavy. Therefore, there is a large movement of weights in the form of tares. This is a source of inefficiency that was not taken into account in this preliminary study.
- Transport systems vary for short and long distances, and in each case the measurable impact is different. A km travelled in the vicinity of the site has proportionally more impact than a kilometre travelled long distance.

Seventh, we had to summarise and interpret both disaggregated and aggregated results, to gain a clearer picture of the building site and consider specific actions for future improvements. Consequently, we broke down the study of the building work into 21 subsystems, which are the most common in building work in Spain.

Tab. 3 *List of subsystems considered in the study*

No. Subsystems	No. Subsystems
1 – Foundations	12 – Locks and metal structural work
2 – Sanitation	13 – Stainless steel and metalwork
3 – Reinforced concrete structure	14 – Electrical and lighting installation
4 – Metal structure	15 – Plumbing and thermal solar energy installation for DHW
5 – Roofing	16 – Sanitary installations
6 – Masonry	17 – Installation of heating, ventilation and air conditioning (HVAC)
7 – Paving	18 – Installation of vents and flues
8 – Rendering and tiling	19 – Sgraffito
9 – Plastering, plaster boarding and ceilings	20 – Lining and cladding
10 – Exterior joinery	21 – Glazing
11 – Interior joinery	

3 Interpretation of results

The information gathered on the weight and transport of products used in the construction of the building led to preliminary results for the individual level of the products, the combined level of each subsystem, and the overall level of the building work.

3.1 For the building work

The overall KxK index for the building work was calculated by adding all of the specific KxK values for each product used. For the particular building under study, this amounted to an absolute value of 149,605,845.21 KxK units (see Table 4). The total weight of the building work was 491,120.03 kg. Thus, we could state that the centre of gravity of supply for products in this building work is at a distance of 304.62 km. This is a fairly high value if we consider that the building is being constructed in a European metropolitan area in which there is high potential diversity of supply sources in the vicinity.

3.2 For the products

Table 4 shows the total weight and distance from the supply point for each of the 45 indexed products. These figures were used to obtain the specific KxK value for each product. Products were then ranked from highest to lowest KxK value. The first observation is the wide variation in the values for the kilogrammes of each product supplied and the kilometres that the products are transported. Consequently, the KxK parameter also varies widely.

The product with the highest KxK value, at the top of Table 4, is fine brick, which has a unit value of 75,000,000 units. At the bottom of Table 4 is MDF, which has a value of 300 KxK units.

Tab. 4 *Specific KxK value for each indexed product, ranked from highest to lowest*

Product	Kilogrammes transported	Kilometres from the origin	KxK
Fine brick	127585.59	585	74,637,567.27
Plasterboard	4874.01	3,145	15,328,775.29
Stainless steel	7393.12	1,587	11,732,874.73
Ceramic tile	27525.52	386	10,624,850.72
PVC	4623.14	1,871	8,649,898.76
M80 cement mortar	46161.24	153	7,062,669.72
HA25 reinforced concrete	101519.15	40	4,060,766.00
Porcelain floor tile	11813.60	206	2,433,601.19
Mineral fibre	1889.96	957	1,808,691.72
Lumber	56112.00	32	1,795,584.00
Plaster	10464.38	153	1,601,049.38
Copper	1189.12	1,050	1,248,576.20
“Onduline” bituminous sheet	1851.00	644	1,192,044.00
Water-resistant sheets	8909.48	123	1,095,866.04
Ceramic	3341.52	318	1,062,603.36
Waterproof paint	1297.79	677	878,604.51
S-275-JR steel	16207.82	35	567,273.71
Spruce wood	3702.00	127	470,154.00
Emulsion paint	387.94	1,009	391,431.46
Cement-based adhesive	6034.63	60	362,078.01
Others	315.00	1,027	323,505.00
Polyethylene	199.79	1,389	277,514.82

Product	**Kilogrammes transported**	**Kilometres from the origin**	**KxK**
Polycarbonate	157.80	1,349	212,872.20
One-coat plastering mortar	6429.47	30	192,883.95
Sanitary ware	3129.60	59	184,646.40
Zamak	122.89	1,349	165,781.31
Glass	7233.00	21	151,893.00
Extruded polystyrene	1160.15	123	142,698.45
Marble	1768.31	78	137,928.34
Butyl rubber membrane	214.40	637	136,572.80
Aluminium	835.09	162	135,284.38
B-500-S steel	19311.66	7	135,181.62
Granite	250.80	534	133,927.20
Oak wood	2327.44	34	79,132.96
HM20 concrete	2910.00	20	58,200.00
Gloss paint	51.28	1,009	51,743.74
Sliding doors/windows	1240.00	27	33,,480.00
Pine wood	366.03	70	25,622.10
“Oxiron” paint	12.76	1,167	14,888.00
Galvanized steel	113.11	28	3,167.14
“Delta Drain SM” membrane	31.87	40	1,274.96
Solid iroko wood	31.55	36	1,135.81
Fire retardant paint	1.00	637	644.96
Geotextile sheet	15.00	40	600.00
Medium-density fibreboard (MDF)	9.00	34	306.00
Total	**491,120.03 Kg**		**149,605,845.20 KxK**

For a simplified view of the situation, we divided Table 4 into quartiles. If we correlate the first quartile’s KxK as a percentage (93.40 %) with its weight as a percentage of the total weight (81.43 %), we find that its impact on transport is slightly above average (the centre of gravity of supply for this quartile is around 350 km). If we correlate the second quartile’s KxK as a percentage (5.26 %) with its weight as a percentage of the total weight (8.84 %), we observe that the transport impact of this group is below average (the centre of gravity of the supply for this quartile is close to 180 km). If we correlate the third quartile’s KxK as a percentage (1.16 %) with its weight as a percentage of the total weight (8.27 %), we can see that the transport impact of this group is far below average (the centre of gravity of supply for this quartile is approximately 40 km). If we correlate the fourth quartile’s KxK as a percentage (0.19 %) with its weight as a percentage of the total weight (1.45 %), we find that the transport impact of this group is also way below average (the centre of gravity of supply for this quartile is also close to 40 km).

3.3 By subsystem

The building work was divided into 21 subsystems. When we ranked the various subsystems by their impact according to the proposed KxK parameter, we found a very wide range of values. To obtain a simplified overview of the situation, we also divided Table 5 into quartiles.

Tab. 5 Specific KxK value for each indexed subsystem, ranked from largest to smallest

No.	Subsystems	Kilogrammes	Kilometres	KxK
8	Rendering and tiling	22.78%	510.91	57.06%
6	Specific area of the building work	26.05%	168.74	21.55%
5	Roofing	17.04%	152.60	12.75%
9	Plastering, plaster boarding and ceilings	1.78%	270.84	2.36%
7	Paving	3.61%	81.16	1.44%
	Sum 1st quartile	**71.27%**		**95.15%**
3	Reinforced concrete structure	14.76%	17.57	1.27%
20	Lining and cladding	0.28%	763.84	1.06%
14	Electrical and lighting installation	0.90%	114.07	0.50%
1	Foundations	5.42%	17.81	0.47%
15	Plumbing and solar energy installation for DHW	0.11%	846.11	0.44%
	Sum 2nd quartile	**21.47%**		**3.74%**
2	Sanitation	0.25%	184.90	0.23%
12	Locks and metal structural work	1.22%	28.00	0.17%
19	Sgraffito	1.04%	30.00	0.15%
13	Stainless steel and metalwork	0.62%	50.00	0.15%
21	Glazing	1.37%	21.88	0.15%
	Sum 3th quartile	**4.49%**		**0.85%**
16	Sanitary installations	0.51%	34.38	0.09%
11	Interior joinery	0.41%	34.00	0.07%
18	Installation of vents and flues	0.27%	50.00	0.07%
4	Metal structure	1.51%	3.50	0.03%
17	Installation of heating, ventilation and air conditioning (HVAC)	0.04%	28.00	0.01%
10	Exterior joinery	0.03%	36.00	0.01%
	Sum 4th quartile	**2.77%**		**0.26%**

The first quartile represents 95.15 % of the total KxK for the building work, whilst its weight is only 71.27 % of the total weight. The second quartile represents 3.74 % of the total KxK for the building work, whilst its weight is 21.47 % of the total. The third quartile represents 0.85 % of the total KxK of the building work, whilst its weight is 4.49 % of the total. Finally, the fourth quartile represents 0.26 % of the total KxK for the building work, whilst its weight represents 2.77 % of the total.

4 Conclusions

Currently, architects are not highly aware of the real weight of their buildings or of how this weight is distributed among the different parts. Their awareness is subjective and is probably strongly influenced by visual appearance. In addition, when architects draw up plans, they do not tend to consider the geographic origin of the building products. The combination of these two factors has a multiplying effect that is evident in the large number of products that are constantly transported by road. This task requires time and energy that could clearly be reduced without affecting the quality of the final architectural result. The reduction in time and energy associated with the supply of products for constructing a building could become another vector of efficiency, and thus help to increase the sustainability of construction works.

Clearly, when a site is selected for a new building, the architects need accurate knowledge of local construction products in the geographic area. Locating a new building on a plot is comparable to situating a new physical element in an economic field of supply and demand that is neither homogenous nor balanced. At the time of its construction, a new building attracts the supply of construction products towards it. The field in which the flows of construction materials take place has changed visibly in the last century, due to several major factors:

- The centralized production of new products in large factories, using industrial manufacturing techniques that require considerable centralized investments.
- The high diversification of lining and cladding; products that have little absolute weight within the entire building work, but have high added value due to their association with style and fashion.
- The increasing complexity of certain components of installations, which have little absolute weight within the entire building work, but are complicated and expensive to manufacture.
- The advertising of construction products that is received constantly by architects. This information comes from global sources and does not promote local efficiency.

Therefore, in each project that is commissioned, some of the time allocated for decision--making must be spent assessing local suppliers. This task could be carried out by the building contractor, who could present alternative local suppliers. Thus, the construction of a building may generate economic wealth in the immediate environment. In each architectural design, the KxK parameter can be assessed to facilitate the task of improving efficiency. Subsequently, the decision-making process could be formalized as follows:

- Always evaluate the capacity of local suppliers first
- Then, as a priority, reduce KxK by focusing on products and subsystems in the first quartile to reduce weight as far as possible or decrease the transport distance
- Finally, quantify the efficiency improvements obtained so that a value can be used to compare the situation before and after the proposed actions.

Regular use of the KxK parameter could be particularly beneficial in building activities that are carried out systematically and repeatedly at various sites in the region, such as in networks of schools, hotels and hospitals that are constructed by the same development company using a standard architectural design. The systematic use of the parameter could lead to quantifiable efficiencies of scale.

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References

[1] WACKERNAGEL, M. Nuestra huella ecologica: reduciendo el impacto humano sobre la tierra. Editorial Libros Arces-Lorn. 2001.

[2] SOLANES, T., CALATAYUD, D., CLARET, C. 34 kg de CO_2. Editorial Líneazero Ediciones. Barcelona, Departament de Medi Ambient i Habitatge, 2009.

[3] WANG, W. Build your own green PC, Editorial McGraw-Hill, 1994.

[4] BECH, J., CAMPINS, M. et al. Medi Ambient i Geologia, no. 15. Editorial Diputació de Barcelona, Servei del Medi Ambient, 1998.

[5] ARNALDOS, J., BARBA, R. et al. Medi Ambient i Tecnologia. Guia Ambiental de la UPC. Editorial Edicions UPC, Barcelona, 1998.