# **Supporting Information**

#### Table S.1. Life cycle inventory for the LCA of the studied beams. Note that the inventory is documented for a reference flow of 1 for simplicity. In the comparison of product systems, a reference flow of 0.87 is applied for the grid 3DCP beams

|  | Solid 3DCP  on-site | Solid 3DCP  prefab | Grid 3DCP  on-site | Grid 3DCP  prefab | Cast beam  on-site | Cast beam  prefab |
| --- | --- | --- | --- | --- | --- | --- |
| Reference flow | 1 | 1 | 1 | 1 | 1 | 1 |
| Transportation  All scenarios:  *Transport, freight, lorry >32 metric ton, euro6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U* | Scenario 1 | Scenario 2 | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 2 |
| 250km, supply of raw materials from import center | 250 km, prefab beam to construction site |  |  | 250km, supply of raw materials from import center |  |
| 50 km, materials to construction site |  |  |  | 50 km, materials to construction site |  |
| 100 km, robot and pump to construction site and back (5 beams printed per construction site). |  |  |  | 50km, formwork to construction site (5 beams casted per construction site). |  |
| Values entered | 52996 kg\*km | 10900 kg\*km | 75590kg\*km | 15100 kg\*km | 45110 kg\*km | 8080 kg\*km |
|  | Import transport of raw materials automatically included by database processes | | | | | |
| Raw materials | 5.65 kg Reinforcing steel {GLO}| market for | Cut-off, U  302 kg 3DCP concrete mix 45 Mpa (see the modeled *3DCP mixture* unit process below) | | 5.65 kg Reinforcing steel {GLO}| market for | Cut-off, U  231 kg 3DCP concrete mix 45 Mpa (see the modeled *3DCP mixture* unit process below) | | 5.65kg Reinforcing steel {GLO}| market for | Cut-off, U  *217* kg Concrete, 40MPa {RoW}| concrete production 40MPa | Cut-off, U | |
| 3DCP mixture | | Material Content | Amount | Unit | | --- | --- | --- | | Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, U | 0,000881 | kg | | Portland Cement 95% (modified process) | 0,275238 | Kg | | Concrete mixing factory {GLO}| market for | Cut-off, U | 2,18E-10 | Units | | Ethylene oxide {RER}| market for ethylene oxide | Cut-off, U | 0,003519 | Kg | | Gravel, round {CH}| market for gravel, round | Cut-off, U | 0,298095 | Kg | | Sand {BR}| market for sand | Cut-off, U | 0,211905 | Kg | | Tap water {Europe without Switzerland}| market for | Cut-off, U | 0,019524 | Kg | | Tap water {Europe without Switzerland}| market for | Cut-off, U | 0,165238 | Kg | | Silica fume, densified {GLO}| market for | Cut-off, U | 0,045 | Kg | | Fibre, polyester {GLO}| market for fibre, polyester | Cut-off, U | 0,0001 | kg |   *Material per kg of 3DCP concrete mix 45MPA* | | | |  | |

| Manufacturing equipment | | Pump: PFT ZP3XXL (240 kg) | | | | --- | --- | --- | | Material content | Amount | Unit | | Electric motor, vehicle {RER}| production | Cut-off, U | 55 | kg | | Inverter, 2.5kW {GLO}| market for | Cut-off, U | 3 | Units | | Steel, low-alloyed {GLO}| market for | Cut-off, U | 114 | kg | | Acrylonitrile-butadiene-styrene copolymer {RER}| production | Cut-off, U | 20 | kg | | Metal working, average for steel product manufacturing {RoW}| processing | Cut-off, U | 114 | kg | | Injection moulding {RoW}| processing | Cut-off, S | 20 | kg |  | Robot: ABB IRB6650S (2250 kg) | | | | --- | --- | --- | | Material content | Amount | Unit | | Steel, low-alloyed {GLO}| market for | Cut-off, U | 2100 | kg | | Cable, unspecified {GLO}| market for | Cut-off, U | 30 | kg | | Powertrain, for electric scooter {GLO}| market for electric | Cut-off, U | 50 | kg | | Electronics, for control units {GLO}| market for | Cut-off, U | 20 | kg | | Casting, steel, lost-wax {GLO}| market for | Cut-off, U | 1600 | kg | | Steel removed by milling, large parts {RER}| steel milling, large parts | Cut-off, U | 10 | kg | | Deep drawing, steel, 38000 kN press, single stroke {GLO}| market for | Cut-off, U | 500 | kg | | Welding, arc, steel {GLO}| market for | Cut-off, U | 20 | kg | | | Wooden formwork:  0.0016m3 Plywood, for outdoor use {RER}| market for | Cut-off, U  0.01hr Power sawing, with catalytic converter {RER}| processing | Cut-off, U | Steel formwork:  200kg Steel, chromium steel 18/8, hot rolled {GLO}| market for | Cut-off, U  200kg Metal working, average for chromium steel product manufacturing {GLO}| market for | Cut-off, U |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Manufacturing equipment lifetime and use | Lifetime: 35 000 hours  Print time: 0.43 hours (26 minutes)  81 395 “reuses” | Lifetime: 35 000 hours  Print time: 0.23 hours (14 minutes)  156 174 “reuses” | 5 reuses | 5000 reuses |
| Manufacturing energy | Robot:  0.768 kW Electricity, medium voltage {DK}| market for | Cut-off, U  Pump:  2.4 kW Electricity, medium voltage {DK}| market for | Cut-off, U | |  | |
| Use stage | Carbon sequestration from the atmosphere for 50 years in indoor exposure conditions.  Calculation method based on literature review and *parameters for carbon sequestration* listed below.  No maintenance assumed (i.e., 50 year lifetime) | | | |
| Parameters for carbon sequestration | Surface area: 2.86 m2  Clinker content: 549 kg/m3  Silica fume content 4.5%  13.1 kg CO2 sequestration from air (negative emission) | Surface area: 7.15 m2  Clinker content: 549 kg/m3  Silica fume content 4.5%  21.8 kg CO2 sequestration from air (negative emission) | Surface area: 2.07 m2  Clinker content: 227 kg/m3  Silica fume content 0%  4.90 kg CO2 sequestration from air (negative emission) | |

| Disposal of concrete | *Year of disposal: 2071 (50 year lifetime of beam).*  *Calculations are relative to weight of cement, rebar or beam*  Inputs:  100% Rock crushing {RER}| processing | Cut-off, U  100% Sorting facility, for construction waste {GLO}| market for | Cut-off, U  100% Sorting facility, for construction waste {GLO}| market for | Cut-off, U  50kg\*km Transport, freight, lorry 16-32 metric ton, euro6 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U  Output  50% weigh -Gravel, crushed {RoW}| market for gravel, crushed | Cut-off, U  27% Gravel, round {CH}| market for gravel, round | Cut-off, U  19% Sand {BR}| market for sand | Cut-off, U  100% Pig iron {RoW}| pig iron production | Cut-off, U | | |
| --- | --- | --- | --- |
| Disposal of manufacturing equipment | *Year of disposal: 2033 (35 000 hours lifetime = 12 years based on 8 production hours per day on average).*  Robot and pump refurbished with 75% efficiency. Avoided production of 0.75 new robots and pumps.  100% weigh Manual treatment facility, waste electric and electronic equipment {GLO}| construction | Cut-off, U  250km Transport, freight, lorry 16-32 metric ton, euro6 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U | *Year of disposal: 2021*  Formwork incinerated after 5 uses.  Avoided heat and power production.  332MJ Heat, district or industrial, other than natural gas {DK}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U  50 km Transport, freight, lorry 16-32 metric ton, euro6 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U | *Year of disposal: 2046*  Formwork recycled after 5 000 uses. Avoided production of pig iron.  50 km Transport, freight, lorry 16-32 metric ton, euro6 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U |

##### Table S.2: Compared beam systems in the LCA

|  |  | B1 3DCP | B2 Grid | B3 Cast |
| --- | --- | --- | --- | --- |
| Metrics | Volume (m3) | 0.144 | 0.11 | 0.096 |
| Concrete (Kg) | 302 | 231 | 217 |
| Surface area (m2) | 2.86 | 7.15 | 2.46 |
| Exposed surface area (m2)\* | 2.28 | 6.57 | 2.07 |
| Concrete mix | Aggregates size | 0-2 mm | 0-2 mm | 8 mm |
| Strength (MPa) | 45 | 45 | 40 |
| Density (Kg/m3) | 2100 | 2100 | 2270 |
| Failure Load | kN | 43.7\*\* | 50.1\*\* | 43.7\*\*\* |
| Lifetime (assumption) | Years | 50 | 50 | 50 |
| Reference Flow LCA | n | 1 | 0.87 | 1 |
| \*Assume only two sides and underside of the beam will be exposed to air after construction, i.e. not covered by other construction materials such as slabs and pillars. \*\* Experimental test data. \*\*\* Calculated value due to cast beam being theoretical. | | | | |

##### Table S.3: Impact categories reported in the LCA

| Impact category | Unit |
| --- | --- |
| Climate change | Kg CO2 eq |
| Ozone depletion | Kg CFC-11 eq |
| Ionizing radiation | kBq U-235 eq |
| Photochemical ozone formation | Kg NMVOC eq |
| Particulate matter | Disease inc. |
| Human toxicity, non-cancer | CTUh |
| Human toxicity, cancer | CTUh |
| Acidification | Mol H+ eq |
| Eutrophication, freshwater | Kg P eq |
| Eutrophication, marine | Kg N eq |
| Eutrophication, terrestrial | Mol N eq |
| Land use | Pt |
| Resource use, fossils | MJ |
| Resource use, minerals, and metals | Kg Sb eq |

##### Table S.4. Assumed 3DCP mix for the case study, based on literature review and experimental data

| Type of material | Quantity (%) |
| --- | --- |
| Cement | 27.5 |
| Fly Ash | 5 |
| Silica fume | 4.5 |
| Aggregates | 51 |
| Water | 16.5 |
| Admixtures | 0.44 |
| PE microfibers | 0.01 |
| Density | 2100 Kg/m3 |
| Compressive strength | 45 MPa |

Supporting Content S.5

*Carbonation sensitivity (1)* was performed by selecting lower and higher constant values (k) during the calculation, resulting in lower or higher carbonation depth as a result. Differing situations were selected where  *Clinker Content (1)* in the cement was changed based on commonly observed clinker values in concrete (62-95%) while still containing the same cement amount. *Transportation* *distance (3)* scenarios were modified based on the maximum transportation distance (500km) in the assumed scenario. *Reuse of manufacturing equipment (4)* scenarios were made for the manufacturing equipment. The plywood formwork ranged from 1-100 uses, the reusable steel formwork from 1000-10000 uses, and the 3DCP cell (robot and pump) ranged from 10.000-100.000 hours. *End-of-Life (5)* scenarios were modeled based on the findings on disposal of concrete in *Section 3.2.5*, and by modifying the recovery potential of the equipment. *Energy use (6)* was based on the assumption of 20% and 100% maximum power rating of equipment from the manufacturers' technical documentation for the robot and pump.

##### Table S.6: LCIA results for impact categories of all beams at midpoint

| Impact category | Unit | B1 on-site | B1 prefab | B2 on-site | B2 prefab | B3 on-site | B3 prefab |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Climate change | *kg CO2eq* | 97.96 | 95.73 | 54.54 | 56.91 | 31.13 | 38.81 |
| Ozone depletion | *kg CFC11 eq* | 9.5E-06 | 8.6E-06 | 5.92E-06 | 6.74E-06 | 6.1E-06 | 5.2E-06 |
| Ionizing radiation | *kBq U-235 eq* | 4.339 | 4.20 | 2.98 | 3.14 | 3.23 | 2.38 |
| Photoche. ozone formation | *kg NMVOC eq* | 0.30 | 0.30 | 0.20 | 0.21 | 0.17 | 0.13 |
| Particulate matter | *disease inc.* | 4.1E-06 | 4.1E-06 | 2.83E-06 | 2.94E-06 | 4.2E-06 | 2.3E-06 |
| Human toxicity, non-cancer | *CTUh* | 1.3E-06 | 1.5E-06 | 1.17E-06 | 1.07E-06 | 9.2E-07 | 9.0E-07 |
| Human toxicity, cancer | *CTUh* | 4.5E-08 | 5.7E-08 | 4.72E-08 | 3.93E-08 | 6.1E-08 | 3.8E-08 |
| Acidification | *mol H+ eq* | 0.35 | 0.36 | 0.24 | 0.24 | 0.19 | 0.16 |
| Eutrophication, freshwater | *kg P eq* | 0.015 | 0.017 | 0.017 | 0.012 | 0.009 | 0.008 |
| Eutrophication, marine | *kg N eq* | 0.098 | 0.098 | 0.07 | 0.07 | 0.051 | 0.043 |
| Eutrophication, terrestrial | *mol N eq* | 1.09 | 1.10 | 0.75 | 0.752589 | 0.59 | 0.48 |
| Ecotoxicity, freshwater | *CTUe* | 1480.29 | 1571.03 | 1080.85 | 1032.069 | 753.80 | 694.85 |
| Land use | *Pt* | 645.07 | 674.68 | 457.30 | 454.18 | 1605.57 | 461.96 |
| Water use | *m3 depriv.* | 10.88 | 11.57 | 9.68 | 9.27 | 11.99 | 6.33 |
| Resource use, fossils | *MJ* | 903.94 | 866.89 | 592.74 | 631.83 | 537.68 | 449.63 |
| Resource use, minerals and metals | *kg Sb eq* | 0.006 | 0.006 | 0.004 | 0.004 | 0.002 | 0.002 |