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# Rebar splices as a replacement of rebar overlapping in reinforced concrete structures – a sustainable design solution.

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**Summary**
The article provides information about the mechanical splicing system of reinforcing bars from a technological and constructive point of view, also examining the regulatory aspects and the important repercussions of this system in terms of environmental sustainability.
Reinforcing bars are generally overlapped over a distance defined by the construction codes that can be considered an average of 50 times the diameter of the rebar.
In the overlap, loads are transferred only through the surrounding concrete: if for some reasons concrete will fail, loads are no longer transferred from one bar to the other, and most probably also the overlap will fail, and the whole structure is compromised.
Mechanical splices are seamlessly connecting the two reinforcing bars together, with or without surrounding concrete. This means several things: structural integrity, safety, design flexibility, etc…, with very limited risks of structural failure even when surrounding concrete is missing.
Mechanical splices allow rebar to be used in its full elastic and plastic domain, while rebar overlapping is limited to the rebar's elastic domain.

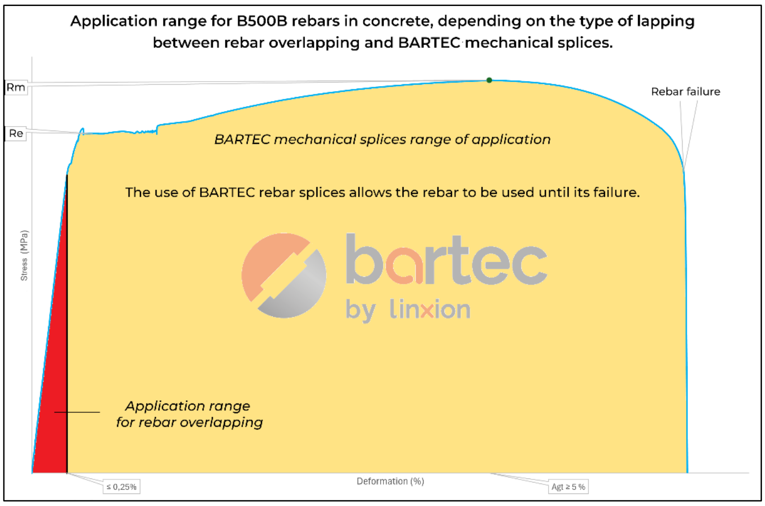




**Image 1 & 2 – Application range in concrete – Mechanical Splice vs Rebar Overlap.**

The original idea of the article is to compare mechanical splices to the traditional overlap under a new different light, since a small coupler bringing all the above technical benefits can weight only the 5% of the equivalent 50 diameters long overlapped rebar.
When used extensively instead of overlap, all together, mechanical splices can bring a reduction of reinforced bars of average 20% while increasing the quality and sustainability of the entire structure. All this at a sustainable cost.
Mechanical joints can be a formidable vehicle for green and sustainable construction: a reduction in steel has the immediate effect of reducing the carbon footprint, not to mention all the side effects of having fewer trucks on the road, less emissions, less energy for loading / unloading unnecessary reinforcing bars, etc...

**Key-words**
Reinforced concrete; mechanical splices; overlapping; reduction of steel; sustainability; green design.

## Introduction

Since the first practical use of reinforced concrete in the 19th century by Mr. Joseph Monier in Paris, going through the experiments and the development made in the United States and Europe, different experiments and development were made in order to find ways to create an effective bond between concrete and steel.

The strength of reinforced concrete depends on this bond between, which is enhanced by their similar thermal expansion properties and strong adhesion To increase the bonding between the two materials, instead of using smooth steel bars, it is common practice since decades to use bars with ribs on its surface.

Because each single reinforcing bar (rebar) must go through a process of manufacturing, transportation, cutting, bending, and delivering to site, it is obvious that for reassembling them on site it is needed a way to connect them in a safe way before casting the concrete into each element.

The first, and easiest, method used to connect two rebars was the traditional overlap (Image 3). In this system, the surrounding concrete, although weak at tension, may guarantee the required strength as long as the embedded rebar overlap is long enough. This length depends on several factors defined by the building code used for the design of the specific element, but it is reasonable to consider it as an average of 50 times the diameter of the reinforcing bar to be spliced.

Because the overlap splice cannot perform efficiently without a proper combination of surrounding stirrups or links, building codes as the Eurocode are also asking and providing indications on how to increase its amount in the splicing region (Image 4).

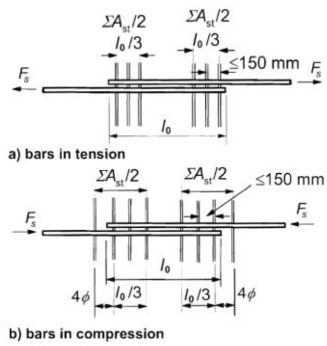


Figure 8.9: Transverse reinforcement for lapped splices

**Images 3 & 4 – Typical Overlap: two rebars side by side for 50Ø & Eurocode indications**

The consequence of adding stirrups is that the amount of steel needed to be fixed next to every splice is higher, as longer becomes the assembly time (plus, in heavier structures, congestion can be an issue).

Mechanical splices were created to replace the overlap in specific “problematic” cases and turned out being an even better solution, becoming a tool for designing more adventurous concrete elements to fit into new landmark buildings.

The best way to describe a mechanical splice and a coupler is to use the definition in one of its main reference norms: the ISO15835: 2018.
§ 3.3 mechanical splice: complete assembly of a coupler, including any additional intervening material or other components providing a splice of two reinforcing bars
§ 3.4 coupler: coupling sleeve or threaded coupler for mechanical splicing of reinforcing bars for the purpose of providing transfer of axial tension and/or compression from one bar to the other where

- coupling sleeve is a device fitting over the ends of two reinforcing bars,
- threaded coupler is a threaded device for joining reinforcing bars with matching threads.

In other words:
A mechanical splice is a device to join two reinforcing bars with the capacity to transfer the full tension from one to the next.

The smallest in size and most popular splice is the threaded system, with two rebars threaded and connected through a coupler sleeve (Image 5):

**Image 5 – Typical parallel threaded splice (©BARTEC)**

Mechanical splices come in a range designed to fulfil all the possible applications: standard, position, weldable, anchors, etc…and also in different material or coating (stainless steel, epoxy, etc…) so that all situations are covered (Image 6).

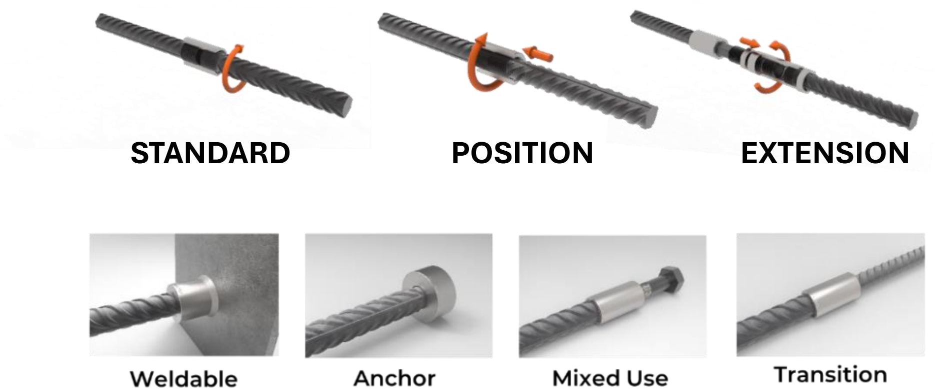



**Image 6 – Examples of typical applications and special splices (©BARTEC)**

Also, we can find special couplers that are designed to fit into high performance splices, in a system with high resistance rebars (with a yield strength of 700 MPa, for example).

Project specifications refer to norms defining all the requirements that splicing systems must have, and criteria to measure its performance through some tests, which may include: Tensile Tests, Slip Tests, Fatigue Tests, choc Tests, Seismic Tests.

Different performances are allowed according to the used norm and design codes. However, it is commonly accepted that 1) a splicing system is technically superior if compared to the traditional overlap; 2) the safest solution is the so called “Bar-Break” splicing system, which guarantees that after a tensile test the failure will always happens outside the splicing region. It means that the mechanical splice is stronger than the parent rebar.

**Image 7 – An example of “Bar-Break” mechanical splice (©BARTEC)**

In addition, the norms on mechanical splices define the criteria for the quality control that a coupler manufacturer must undergo during its production process: by providing that, the norm is ensuring that only a manufacturer with a solid QC system can supply couplers.
Independent certification bodies, like CARES (UK), AFCAB (France), ICC (USA), DIBT (Germany), etc… take in charge the assessment of a factory according to the reference norms, through regular audits to its premises, traceability inspection, and independent testing on couplers randomly selected out of the manufactured batches.

With a certification from an independent body, the quality of a splice is guaranteed, and because mechanical splices are a structural device, it is always recommendable to use certified splicing systems to make sure that its performance is exactly as expected by the designers who specified it.

Although a mechanical splice can replace an overlap splicing without any limitations, its usage is not as extensive as it could be, and only a few countries do consistently specify mechanical splices in most of its local construction projects. This is due to different reasons: 1) there is not enough literature available to provide the needed technical information and knowledge on couplers, 2) there is not always a local lab or organization able to certify mechanical splices, 3) couplers may not be locally available, 4) there is still a perception that it is a new and expensive solution.
None of the above reasons is merely technical.

**Technical and constructive advantages**

As a matter of fact, overlap is the traditional way of connecting reinforcing bars into a structure.
Reinforcing bars are generally overlapped over a distance defined by the construction codes that can be considered an average of 50 times the diameter of the rebar (e.g.: 125 cm for a 25 mm rebar) and fixed into position with a steel wire that has not any structural purposes other than keeping rebars together before casting the concrete.
It goes without saying that not being the two rebars physically connected together, loads are transferred only through the surrounding concrete, which means, in other words, that if for some reasons concrete will fail (corrosion, damage from earthquake on poorly designed structures, etc…), most probably also the overlap will fail, and the whole structure is compromised (Image 8).

**Image 8 – Overlap in a column (©BARTEC) and Overlap Failure (Internet)**

Mechanical splices are seamlessly connecting the two reinforcing bars together, to the point that the reinforcing bar behaves like a continuous bar, with or without surrounding concrete. This means several things: structural integrity, safety, flexibility, etc…but more than everything it means that in case of failure of the surrounding concrete, the rebar cage underneath is not affected, and the risks of structural failure are very limited.
Thanks to its "continuous rebar" behavior it becomes immediately clear that mechanical splices are not just "an alternative to the traditional overlap".

**Image 9 – Mechanical splices in a column & Spliced rebars are not affected by the failure of surrounding concrete (2017 earthquake Mexico City – Internet)**

**Technical advantages**

- Safe Solution: as loads are not depending on the surrounding concrete, risks of structural failure are very limited. Mechanical splices are also tested to low and high cycle fatigue, meaning that these criteria should guarantee its strength when they are exposed to extreme load situations. If "bar break" mechanical splices are used (i.e. mechanical splices where the tensile failure happens systematically outside the splicing region) the splicing would be much stronger than the rebar itself, which means even more safety.
- Certified Technology: a certification is synonymous of continuous quality control, material testing, traceability, etc…a certified mechanical splice is guaranteeing that what is installed on site according to the instructions provided by the manufacturers performs exactly as expected by the designers who specified the mechanical splice solution. Each coupler is marked with a code indicating type of couplers, manufacturer, size, batch number, so that it is possible to check all its history just by checking its marking. There are not any reported structural accidents, ever, where certified couplers were installed.
- Avoid Congestion and Build Solid Elements: when the structure becomes more complex, the concentration of reinforcing bars in some sections of the elements becomes very challenging for a correct rebar fixing, and even more challenging for a proper concrete casting, as the flow of the aggregates is quite difficult. Using mechanical splices will reduce to half the amount of the steel rebars in the splicing region, making the process easier and more accurate, and guaranteeing that the phase of concrete pouring is properly accomplished with the correct filling of all empty spaces. The result will be a more solid and durable concrete element.
- Extra Strength from the Surrounding Concrete: the technical limit of the traditional overlap to be secured by the bonding concrete becomes an advantage for mechanical splices. As mechanical splices are normally tested and certified in air, with criteria asking for performance similar to the parent rebars, it becomes obvious that once splices are cast into concrete, the surrounding concrete can only deliver extra strength to the connection.
- Design Flexibility: one of the main reasons why mechanical splices have been developed is to allow the design of concrete elements for specific situations, either for futuristic buildings, or for reducing the size of the elements to the minimum for need of more space around it, or for other reasons like increasing commercial surface.
- "Bar-Break" mechanical splices allow rebar to be used in its full elastic and plastic domain, while the traditional rebar overlapping is limited to the rebar's elastic domain.

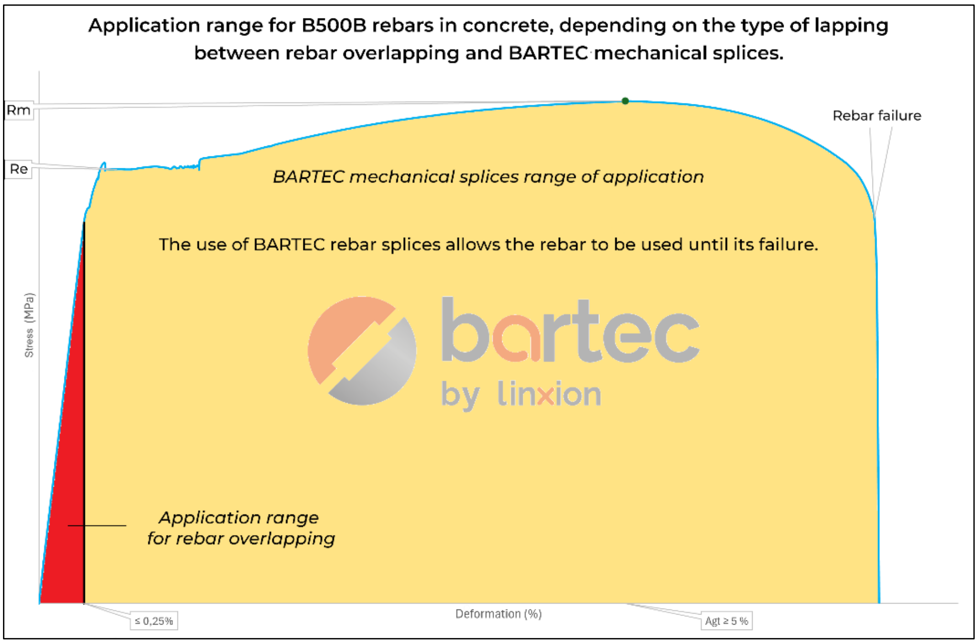



**Image 10 – Application range in concrete**

**Constructive advantages**

- Formworks Saving: when mechanical splices are used, there are no protruding rebars that need to go through the formworks. This means that 1) formworks do not have to be prepared and drilled beforehand, 2) they can be reused over and over, with a lot of time and economic saving.
- Prefabrication of Cages: one of the biggest benefits of using mechanical couplers to its maximum extent is when rebar cages are designed to be prefabricated in a workshop, and then assembled on the job site. Eliminating the time for preparing and fixing complex elements of rebars on site can speed up enormously the operations. It has been proven that also elements with rebars of big diameters can be installed and precisely positioned on the site, and then secured with mechanical splices. When this constructive method is exploited to its maximum extent, the time saving may be terrific.
- Climbing Formworks: high rise buildings construction can be optimized and sped up by using climbing formworks. Only by using devices like mechanical splices it is possible to build the slabs anchored to the core elevator shafts and move up very fast. This is a typical example of construction in phases, where the couplers, normally protected by plugs, are used to splice second phase horizontal bars after the completion of the vertical wall concrete casting.
- D-Walls/Top-Down Structures/Future Extensions: other examples of construction in phases are D-Walls, typical of metro station constructions, where a rebar cage with horizontal couplers already installed at the slab levels is previously inserted into the ground. A similar method is used for top-down structures, where also vertical elements can be extended while the excavation proceeds downwards. Last but not least, mechanical splices cast into concrete on the roof of a building can be used for a future extension without a need to leave protruding rebars exposed to the natural elements.
- Less Splices in Longer Elements: when we assume 50 diameters for overlap while considering the construction of a 60 m vertical column with 40 mm rebars, we will need to splice 6 rebars of 12 m length, since we lose 2 meters for each splicing. If mechanical splices are used, we only need to splice the rebars 5 times. This operation will save time and handling energy, indeed, and even more time if pre-assembled cages are used!

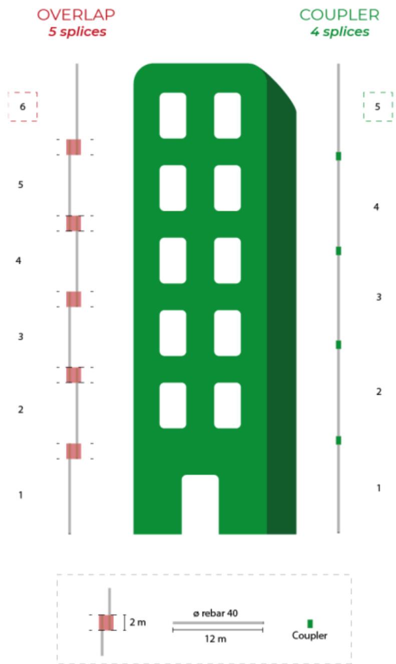



**Image 11 – Mechanical splices help reducing construction phases and save time (©BARTEC)**

- Precast Concrete Elements: mechanical splices can be used as part of the precast elements. Once they are integrated into the process, components may be designed to be easily and safely connected on site, enhancing the quality of the building, and reducing the assembling time.
- More Safety on the job site: as each mechanical splice is avoiding an extra protruding reinforcing bar with a length of 50 times its diameter, it is obvious that the safety on the site can only increase because of less obstacles on the way.

**STARS project and green building benefits**

All the above advantages are the typical advantages of mechanical splices. However, there is another main advantage that becomes more and more important, which is the huge impact on the environment when mechanical splices are used instead of the traditional overlap, simply due to the fact that each coupler is replacing a piece of reinforcing bar much heavier than it.

Until today mechanical splices have been considered as a specific solution aimed at bringing consistent technical and constructive advantages to reinforced concrete structures. They have never been seen as an effective replacement of the overlap to reduce the steel amount in concrete elements, which, in addition, would only have a lot of positive "side effects", like less emissions, less trucks on the roads, less energy for loading-unloading, etc…

The project STARS (Splicing Technology Allows Reduction of Steel) has been developed with the aim of showing the green potential of mechanical splices, a safe and well-known technology that may bring top extra valuable advantages to the environment.

**Image 12 – STARS Logo (©BARTEC)**

STARS has been presented for the first time in March 2022 in Dubai, a place that was chosen 1) for the large amount of futuristic projects present there, either already realised, or in development, 2) because in Dubai mechanical splices are already used extensively (but not enough to fully exploit their green potential, as we will see later), and 3) for the declared commitment of the UAE government to achieve a Net Zero emissions by the year 2050.

The event was promoted and conducted by Linxion International (a branch of Linxion The Original), and actively supported by EGBC (Emirates Green Building Council), CARES (the UK Certification Body), and IStructIE (Institute of Structural Engineers), and had the goal to present mechanical couplers as a mean of reduction of the emissions coming from steel rebars.

Before going any further into the subject, it is necessary to clarify the following:

1) it is clear that a lot more factors and variables present in the steel supply chain should be considered when evaluating the actual carbon footprints; however, the results after doing the comparation in its basic terms were such that it was evaluated that other elements, although they have its importance, may have a minor impact for the purpose of this study, and therefore were not considered. We believe that this is a very first step into something of great value that should be developed more in detail, and we invite all experts who may want to give a contribution to join the STARS Project.

2) As STARS was developed and conducted by Linxion the Original, the size and technical data of BARTEC/LINXION splicing systems were used for all the simulations. Other splicing systems of bigger size may lead to less relevant conclusions.

The first part of the STARS investigation is basically comparing the weight of the extra reinforcing bars in the overlaps with the weight of the equivalent splicing systems (i.e.: the weight of couplers).

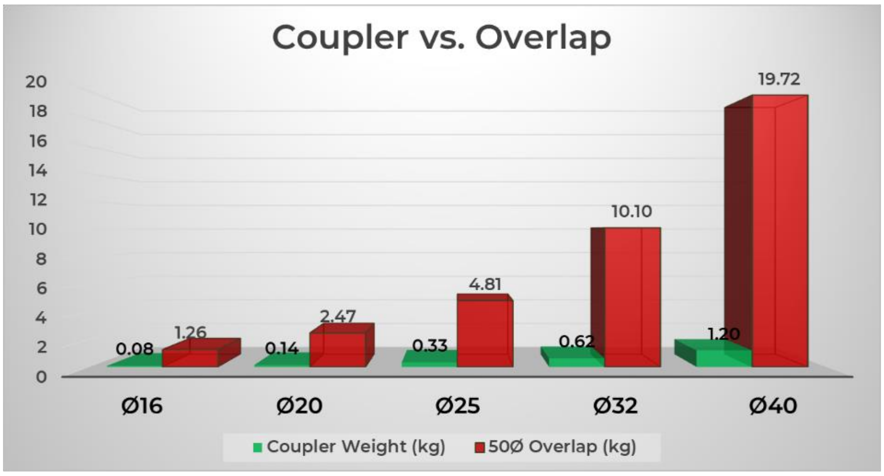



**Image 13 – Weight chart Coupler/Overlap (©BARTEC)**

Image 13 shows the weight of couplers of the most used sizes compared to the weight of the equivalent overlapped reinforcing bar. While the weight of couplers grows in a linear way with the diameter, the weight of the equivalent rebars is increasing exponentially.

**A case study: Grand Paris**

To understand the impact of the above in the reality, we considered the Grand Paris project, 200 km railway extension around the city of Paris, where mechanical splices are used quite extensively. Only in 2021 Bartec by Linxion delivered to this site 320.000 couplers in different sizes.
When we do the same exercise of comparing the weight of all the delivered 320K couplers with the weight of what would have been the equivalent reinforcing bars, we get the following results:

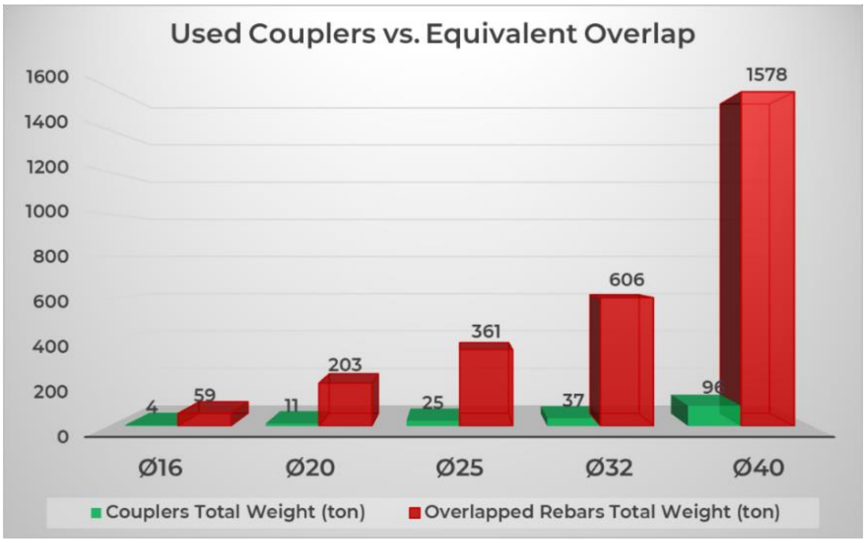



**Image 14 – Breakdown of weight/size of couplers and overlap (©BARTEC)**

Image 14 shows the breakdown of the different sizes of rebars. The total amount of steel saved thanks to the couplers after grouping all together (= total overlap extra rebars – couplers weight) was over 2.600 tons (!) only in year 2021 for mechanical splices used in a small portion of the project, and for specific applications.

Steel mills are among the biggest responsible of industrial $CO_2$ emissions, and even considering similar $CO_2$ emissions for the production of couplers and rebars, we can say that the $CO_2$ footprint coming from couplers is only 6% compared to the equivalent traditional overlap.
Moreover, 2600 extra tons of rebars must be transported on 108 heavy trucks traveling from the mill to the workshop, unloaded, reloaded, and finally delivered to the job site located several km away through the road

network (in this case the Paris suburbs)…when using mechanical splices you only 8 trucks! not to have to be loaded, unloaded, not engaging the road network: less traffic, less energy consumption, less emissions, etc…

After this first analysis a few relevant facts can be pointed out:

- Mechanical Splices are a green solution compared to Overlap, as they can save a lot of tons of steel.
- Most of the biggest projects use couplers for a limited number of applications, so the real potential of steel saving may be much higher, indeed.
- Mechanical splices are technically superior to the traditional overlap.
- Existing rules and certifications guarantee the efficiency of mechanical splices.

The above findings drove the team of STARS to investigate more deeply into the subject and try to check what would happen if instead of using mechanical splices for a few applications, they were used to replace all the traditional overlaps in a structure.

To do that, the main challenge is to calculate how many splices there are into a building, simply because the final design of cut and bent rebars may change until the last day in the construction process. Moreover, the total number of splices depends on many variables: type of structure (bridge, high rise, small villa, tower, NPP, etc…), structural element (column, beam, slab), rebar diameter and grade, construction code, application (seismic, corrosion, fatigue), etc.

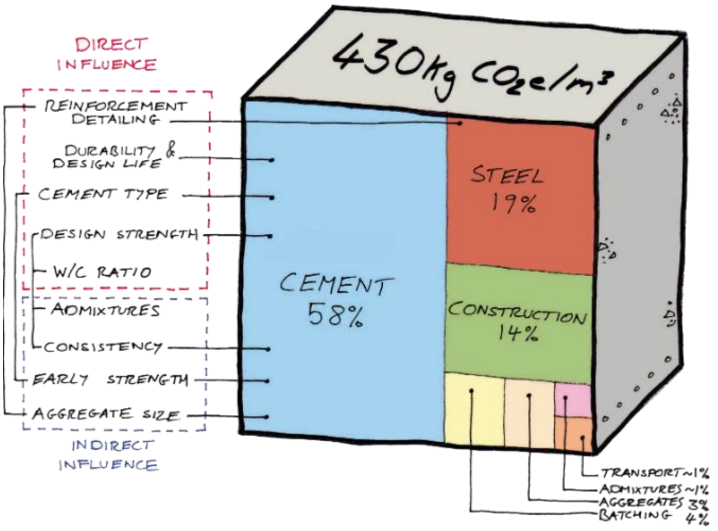
Some statistics were built based on real figures coming from the actual cuts of the rebars for projects of different type and size, which are recorded in the software of C&B workshops (powered by ARIADIS).

The analysis of the logs of Cut & Bend machines on several different construction projects for different diameters between 16 and 40 mm converged, quite unexpectedly, to a single figure, still quite conservative and valid for all diameters, which is one splice every six meters of rebar.

Using that figure, it is possible 1) to calculate the total amount of splices for any project, based on the breakdown by size of the rebars needed for it, and 2) to compare the total weight of the overlaps with the total weight of the equivalent couplers.
This exercise was conducted on a few projects, with the surprising result of a reduction of the quantity of steel of 20% for a residence building, and 24% for a two towers bridge:


**Image 15 – All mechanical splicing simulation on two projects (©BARTEC)**

In order to give a "green" meaning to the above figures, a study conducted by IStructE, showing the components of the embedded carbon in a finished building was taken as a reference, where we can see that the part of embedded carbon due to the reinforcing bars is an average 19% of the total.




*Based on the following assumptions: 300kg/m$^3$ cement with average additions (0.83kg$CO_2$ e/kg); 100kg/m$^3$ steel (0.84kg$CO_2$ e/kg); water–cement ratio = 0.5; 20mm aggregate; placed in situ; 11km transport distance; construction value based on a total construction rate of 30kg/m$^2$ (250mm concrete/m$^2$ and 50% emissions allocated to structure).*

**Image 16 – Embedded Carbon in a building (published on www.thestructuralengineer.org February 2021)**

If we consider an average 20% of steel reduction because of mechanical splices, we have a reduction of embedded carbon in a building of 3.8%, which is quite impressive when considering:

- The well-known global huge impact of the carbon footprint coming from the construction sector.
- The increased durability of the structure when mechanical splices are used.
- The clear directions of all governments towards designing structures with less emissions.
- The positive “collateral effects” of removing trucks from the roads, reducing the job site duration, etc…
- The immediate availability of an effective solution against the Global Warming EMERGENCY that we are facing.

The importance of these findings already suggests to adopt it as a standard solution for all structures, however we need to understand if its cost is sustainable.

**Cost considerations**

As a matter of fact, mechanical splices are normally compared to the mere cost of the extra plain steel rebar length of 50 diameters of the equivalent overlap. This is not “technically” correct, as it is a comparation between a device behaving like a continuous rebar to something in need of surrounding concrete to transfer loads.

Following our studies made with some projects and with market prices in Dubai, the impact on the costs when using all couplers instead of overlaps is always less than 0.7%, for the whole project using rebars of diameter 16mm and above, if simply calculated in comparison with the cost of the overlapped length of rebar,

However, more elements should be considered in this comparison, like:

- Steel rod: as small as it is, the quantity of steel rod used to tie rebars together comes with a cost.
- Extra stirrups: in the area of overlap splicing, all norms ask to add extra rebars (stirrups) to give extra reinforcement against cracking and prevent the element to become a weak point of the structure.
- Overlap Length: it is normally accepted to consider the overlap length 50 times the rebar diameter. Although this is true in most of the cases, some codes are requiring for longer overlaps for specific reasons (e.g. seismic design), which means that more material may be actually needed.

Rebars quantity is directly proportional to the amount of overlaps, which means that more material means more trucks, more scrap, etc.
…and more costs, typical of the overlap solution, like: formworks preparation, extra assembly time in congested areas, longer construction time, variable rebar price during project execution, etc..

On the other hand, the cost of a mechanical splice is calculated as the cost of the rebar preparation plus the cost of the sleeve.
In case of a threaded splice, we would have one coupler plus two threads.

Unlike the case of the overlap, steel has very low impact on its price, and no more variables nor other costs less evident need to be considered, which means that what is specified can be properly and univocally quoted. In a nutshell, once the price of the mechanical splice is agreed with the supplier, its cost is fixed for the project duration!

Moreover, an extended usage of mechanical splices would have as a consequent a consistent drop of its price in the market.
Therefore:

- It is not correct to assume that the cost of an overlap is only cost of the plain rebar 50Ø length.
- The Overlap Price for the end user is variable, rather towards the higher side!
- The more mechanical splices are used the more the gap between the cost of mechanical splices and overlap is reduced (or increased in case of the bigger sizes).
- Using only mechanical splices would reduce the heavy traffic on the roads, and the scrap material.
- The technical and constructive benefits of mechanical splices result in a more solid and durable structure.

## Conclusions

It has been ascertained that mechanical splices are a solution technically superior to the traditional overlap to consistently reduce the amount of rebars into a building, while increasing its strength and durability.

The effects for sustainability of rebar quantity reduction are terrific, as 20% less steel means 20% less heavy trucks on the road, 20% less GHG, better condition of the road networks, etc...

The solution is already available and tested since many years, building codes are ruling it, and certification bodies are checking it. The effect on the environment of an extended use of it would be immediate.

At this very low added cost, there would be a reduction higher than 3% of the embedded carbon in the buildings, which is a huge benefit for the environment, and responds to the present guidelines for a greener and sustainable construction.

## References

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO15835 - Steels for the reinforcement of concrete — Reinforcement couplers for mechanical splices of bars. 2018.