



Copper-Mediated Synthesis of (E)-1-Azido and (Z)-1,2-Diazido Alkenes from 1-Alkene-1,2-diboronic Esters: An Approach to Mono- and 1,2-Di-(1,2,3-Triazolyl)-Alkenes and Fused Bis-(1,2,3-Triazolo)-Pyrazines

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Copper-Mediated Synthesis of (*E*)-1-Azido and (*Z*)-1,2-Diazido Alkenes from 1-Alkene-1,2-diboronic esters. An Approach to mono- and 1,2-di-(1,2,3-Triazolyl)-Alkenes and Fused bis-(1,2,3-Triazolo)-Pyrazines.

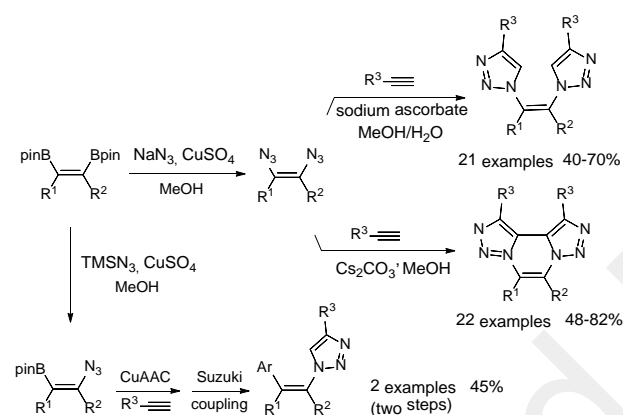
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This article is dedicated to P.H. Dixneuf for his exceptional contribution to organometallic chemistry and catalysis.



ABSTRACT: A stereoselective and convenient route has been demonstrated to access (*Z*)-1,2-diazido alkenes from the corresponding 1,2-diboronic esters *via* a copper-mediated reaction with sodium azide. Alternately, the mono-functionalization was regioselectively carried out with trimethylsilyl azide as azidation reactant. The *in situ* conversion of bis-azides to the corresponding bis-triazoles can be readily achieved in the presence of copper sulfate and sodium ascorbate, while the modification of the catalytic system opened a new convenient route to bis-triazolo-pyrazines, a new class of fused heterocycles.

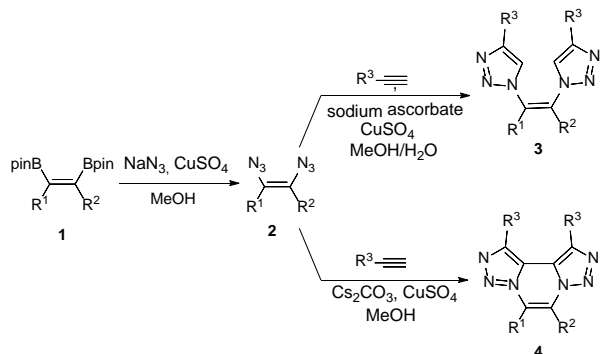
INTRODUCTION

Azides play a pivotal role in synthetic organic chemistry as central building blocks for the construction of numerous nitrogen containing heterocyclic compounds.¹ Among the vast family of azido compounds, open-chain 1,2-diazido alkenes have been rarely described unlike their (hetero) aromatic analogues.² They were usually prepared from electron-withdrawing group-substituted propargyl azides or 2-azido-3-halo cinnamaldehydes.³ The photolysis of these vicinal alkenyl diazides afforded at low temperature 2-azido-2*H*-azirines that decomposed to nitriles on prolonged irradiation or heating.⁴ If alkenyl boronic acids and esters have been already employed as efficient precursors of the corresponding vinyl azides,^{5,6} which in turn can be easily converted to triazoles,⁷ 1-alkene-1,2-diboronic esters were never engaged in similar sequence despite the major interest of the resulting bis-

triazoles.⁸ Such compounds have indeed found numerous valuable applications in various areas ranging from life science to organometallic chemistry. For example, were reported remarkable biological properties, including anti-cancer,⁹ antibacterial,¹⁰ antifungal,¹¹ anti-diabetic¹² and antibiofilm activities,¹³ urease or transaminase inhibition,^{14,15} and modulation of protein-protein interactions.¹⁶ Bis-1,2,3-triazoles were also used as ligands of various metal complexes,^{17,18} chiral organocatalysts,¹⁹ or in stereodivergent anion binding catalysis.²⁰ In connection with our research interest focused on the use of organo bis-boranes as versatile intermediates in heterocyclic chemistry,^{5a,5c,21} we report here an easy and stereoselective synthesis of (*Z*)-1,2-diazido alkenes **2** and their *in situ* conversion to the corresponding bis triazoles **3** (Scheme 1). A simple change of the catalytic system for the cycloaddition step opened the way to hitherto unreported fused bis-(1,2,3-triazolo)pyrazines **4**. In parallel, mono azidation of bis-

boronates was also developed under different azidation conditions.

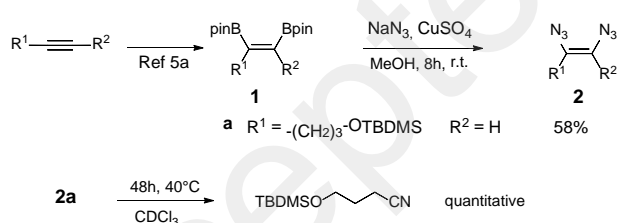
Scheme 1. Synthesis of (Z)-di-(1,2,3-Triazolyl)-Alkenes and Fused bis-Triazolo-Pyrazines from 1-Alkene-1,2-diboronic Esters



RESULTS AND DISCUSSION

We initiated our studies with pinacol 1,2-diboronic ester **1a** which was easily prepared by diboration of *tert*-butyldimethyl(pent-4-yn-1-yloxy)silane with bis(pinacolato)-diboron *via* platinum catalysis.^{5a} In compliance with strict safety rules related to the handling of azido compounds (see Supporting Information), this bis boronate was converted in a 58% yield to the (Z)-1,2-diazo alkene **2a** by treatment with sodium azide and copper sulfate in methanol (Scheme 2). This transformation occurred with retention of stereochemistry of the initial double bond.²² This compound, that could be purified by chromatography on silica gel, slowly decomposed at room temperature to afford 4-(*tert*-butyldimethylsilyloxy) butyronitrile.²³ This conversion is complete after 48h at 40°C. If such transformation was already reported, the exact mechanism remains still unclear.^{4,24}

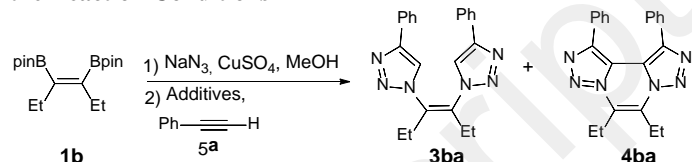
Scheme 2. Synthesis of (Z)-1,2-Diazoalkenes from 1-(Z)-Alkene-1,2-Diboronic Esters



Due to the potential instability of 1,2-diazoalkenes, the further reactions were carried out in a one-pot manner without isolation of these intermediates. We initiated the cycloaddition studies with the *in situ* generated **2b** ($R^1 = R^2 = \text{Et}$), selected as example. It was first trapped with phenyl acetylene **5a** in the presence of sodium ascorbate (Table 1, entry 1). Besides the presence of the expected bis-triazole **3ba**, examination of the crude mixture by ¹H NMR revealed the presence of another product **4ba** (**3ba/4ba** = 80/20). These two compounds were easily separated by column chromatography and the determination of their exact structures was done by X-ray crystallography in agreement with NMR data and mass spectroscopy.²⁵ The formation of a coupling product in copper-catalyzed azide-alkyne cycloadditions (CuAAC) was first notified by

Sharpless and co-workers.^{7f} Later, Angell and Burgess developed the first preparative access to these hitherto underexplored heterocycles.²⁶ More recently, several other reports described the influence of experimental conditions on the efficiency of this process.²⁷ On the basis of these results, various reaction conditions were then examined in order to optimize the formation of either of these compounds (Table 1).

Table 1. Synthesis of (Z)-1,2-di(1,2,3-Triazolyl)-Alkenes and Fused bis-(1,2,3-Triazolo)-Pyrazines. Optimization of the Reaction Conditions



| Entry | Additives (mol %) | Solvent | 3ba/4ba ^a |
|-------|---|--------------------------------|-----------------------------|
| 1 | CuSO ₄ (100) sodium ascorbate (60) | MeOH ^b | 80/20 |
| 2 | CuSO ₄ (100) sodium ascorbate (60) | MeOH/H ₂ O (1/1) | 100/0 ^c |
| 3 | CuSO ₄ (100) K ₂ CO ₃ (100) | MeOH | 55/45 |
| 4 | CuSO ₄ (100) Cs ₂ CO ₃ (100) | MeOH | 17/83 |
| 5 | CuSO ₄ (100) K ₂ CO ₃ (100) | MeOH/H ₂ O (1/1) | 79/21 |
| 6 | CuSO ₄ (100) Cs ₂ CO ₃ (100) | MeOH/H ₂ O (1/1) | 39/61 |
| 7 | CuSO ₄ (100) Cs ₂ CO ₃ (25) | MeOH | 10/90 ^d |
| 8 | CuBr (100) Cs ₂ CO ₃ (100) | MeOH ^b | 68/32 |
| 9 | CuSO ₄ (100) Cu (10) Na ₂ CO ₃ (100) | MeOH | 52/48 |

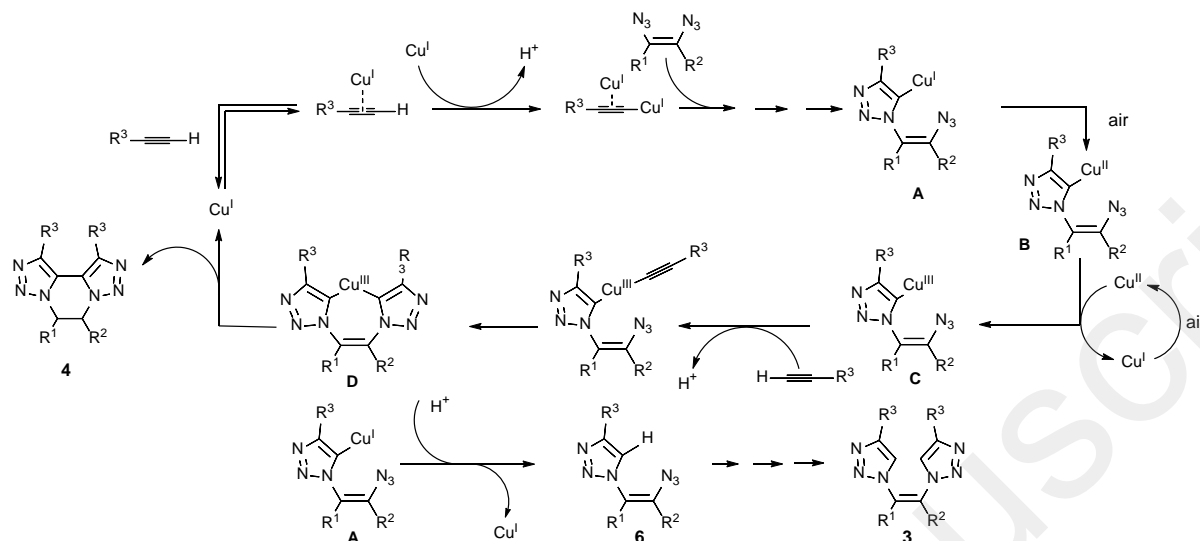
^a The ratio **3ba/4ba** was determined by ¹H NMR. ^b HPLC grade methanol without prior drying. ^c Isolated yield for **3ba**: 70%. ^d Isolated yield for **4ba**: 82%.

The modification of the initial procedure (Entry 1) by using a 1/1 mixture of MeOH/H₂O as solvent significantly improved the formation of **3ba** (Entry 2). This beneficial effect in detriment to the bis-(1,2,3-triazolo)-pyrazine was confirmed with other catalytic systems (Entries 4 and 6). As previously reported,^{27f, 28} the presence of sodium ascorbate as reductant was not necessary to carry out the cycloaddition and its replacement by a base notably increased the production of **4ba** (Entries 3 and 4 *versus* 1 or 5 and 6 *versus* 2). Cs₂CO₃ is more efficient than K₂CO₃, the best ratio **4ba/3ba** being observed with 0.25 equiv of base (Entries 4 and 7). No improvement was found by switching CuSO₄ to CuBr or with the addition of Cu metal (Entries 8 and 9). It is worthy to note that the involvement of a Cu(I) oxidation state is usually required to carry out the cycloaddition. When copper sulfate is used, the co-addition of a

reducing agent such as sodium ascorbate (Table 1, entry 1) or elemental copper (Table 1, entry 9) is thus necessary. However, in their absence, the reaction can still be performed, the

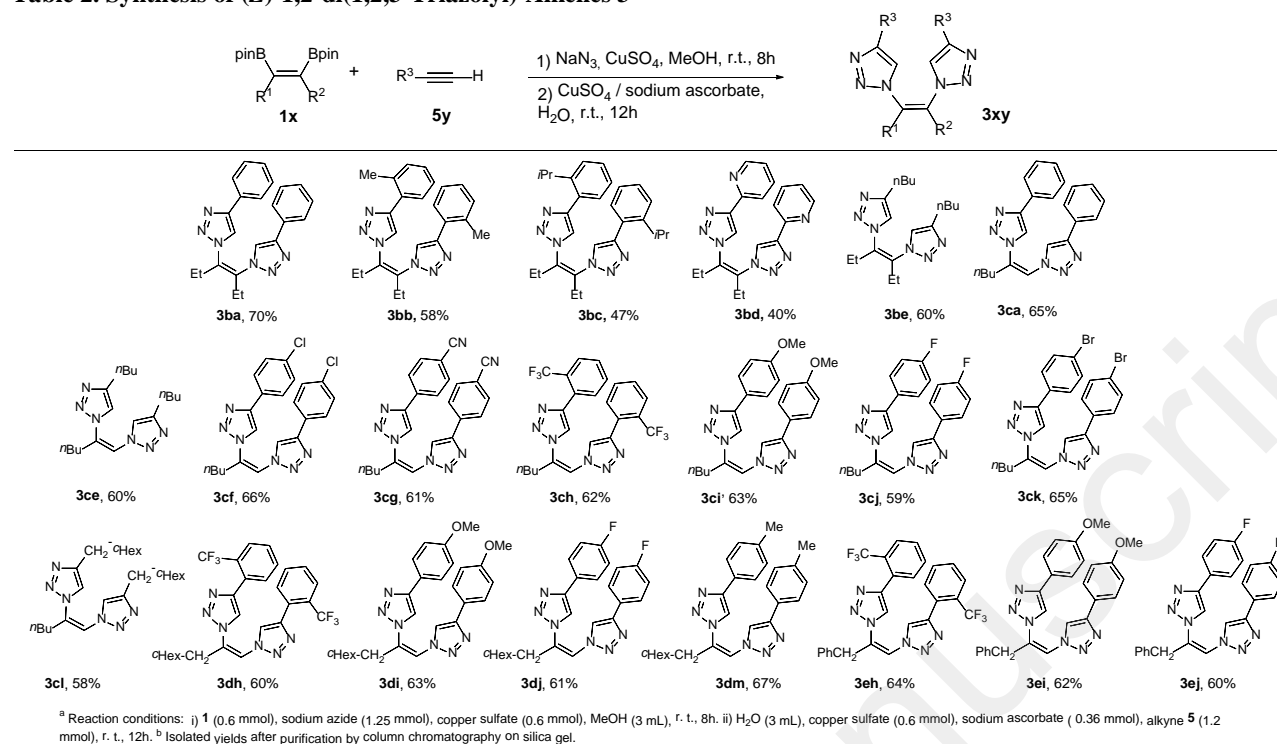
needed Cu(I) being then generated by alcohol oxidation or alkyne homocoupling.²⁹

Figure 1. Proposed Reaction Mechanism of Formation of 3 and 4 (only the Redox States of Cu are Shown for Simplicity)



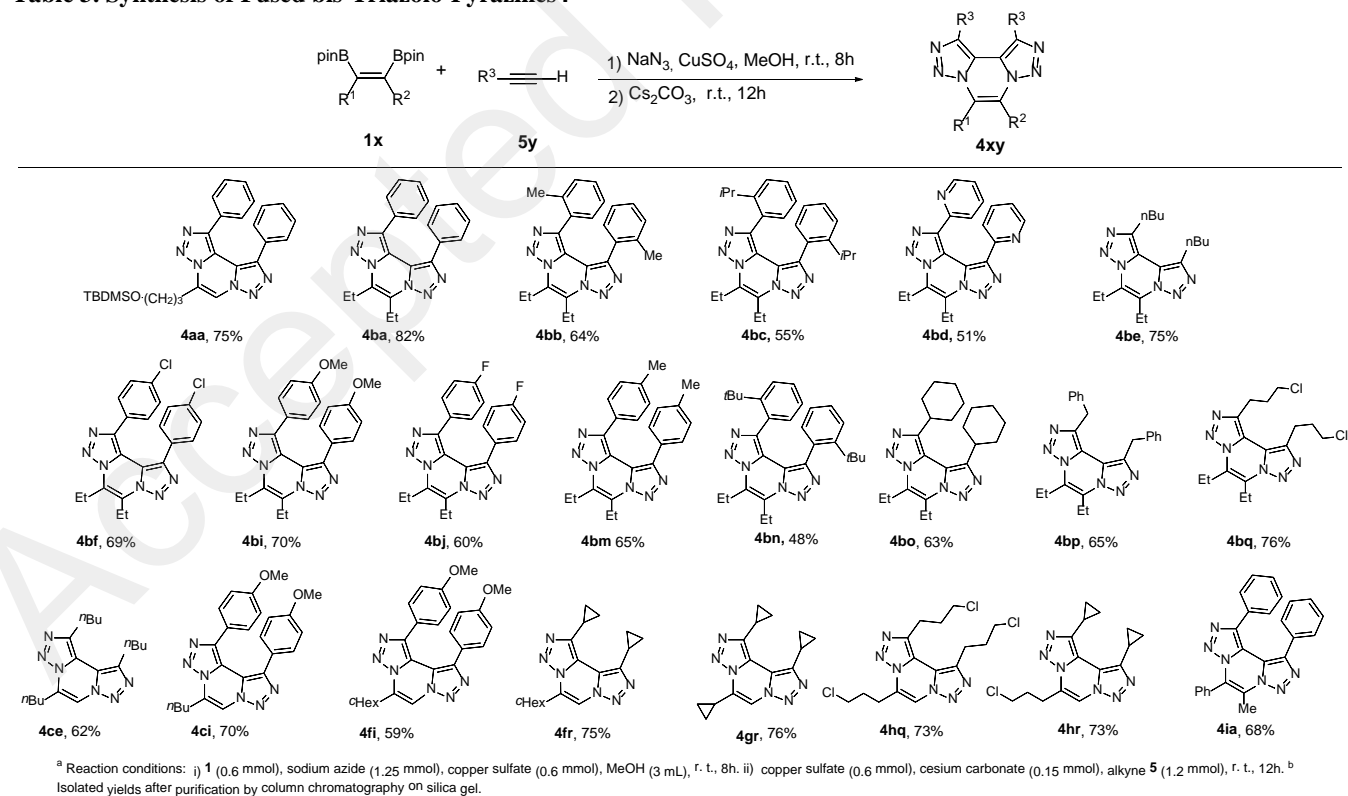
Regarding the possible reaction mechanism, the formation of a copper triazolide **A** (Figure 1) probably first occurred *via* a dinuclear copper species, an intermediate now commonly proposed in such a cycloaddition.^{30, 31} On the basis of the work of Vilhelmsen and Nielsen *et al* about the Glaser–Hay coupling of two terminal alkynes,³² this step would be followed by oxidation to Cu^{II} -triazolide **B**. Another Cu^{II} species would cause disproportionation to generate a Cu^{III} complex **C**. After coordination of a second acetylide and intramolecular cycloaddition, reductive elimination would give the bis-(1,2,3-triazolo)-pyrazine **4** and Cu^I which can enter in a new catalytic cycle. The protonation of **D** would provide mono azide **6** which would be engaged in a new CuAAC sequence to afford **3**. This compound could be also produced directly from **D** and

a proton source. The scope of our approach to access **3** or **4** was then evaluated with various alkynes according to the best experimental conditions previously determined (Table 2). The use of a mixture of copper sulfate and sodium ascorbate in 1/1 MeOH/H₂O allowed the synthesis of a series of (*Z*)-1,2-di(1,2,3-triazolyl)-hex-1-ene **3ba-3ej** from the corresponding diboronic esters **1**. A large range of arylacetylenes containing electron-withdrawing or donating groups can be used with no apparent influence of the nature or position of the aromatic ring substituent. Yields varied from 40 to 70%, whether **1** was tri- or tetra substituted. Similar results were obtained with alkylacetylenes and the presence of a nitrogen-containing heterocycle as pyridine was also well tolerated, albeit with lower yield.

Table 2. Synthesis of (Z)-1,2-di(1,2,3-Triazolyl)-Alkenes 3^{a,b}

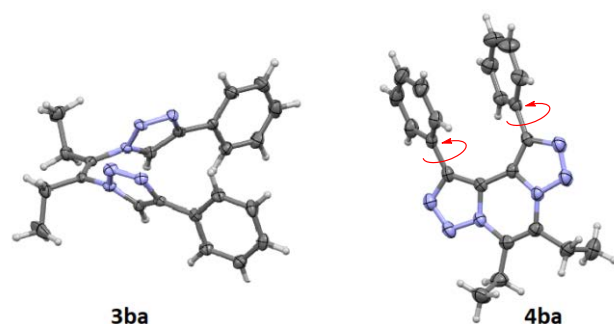
The optimal reaction conditions found to be effective for generating a coupling product (Entry 7, Table 1) were then applied to a variety of structurally diverse bis-boronates and alkynes. Alkyl and aryl-substituted bis-triazolo-pyrazines were obtained in 48 to 82% yields (Table 3). As previously, steric

hindrance at the ortho position of the aryl group notably reduced the yield of the desired product. It is worth noting that this route to bis-triazolo-pyrazines induces the formation of five bonds in one chemical step with complete atom economy.

Table 3. Synthesis of Fused bis-Triazolo-Pyrazines 4^{a,b}

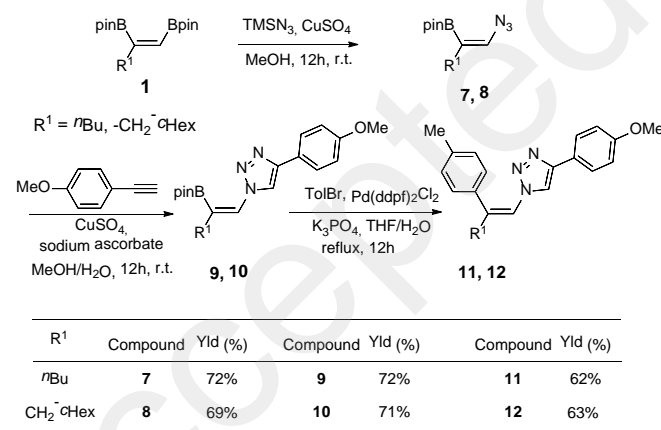
If the RX structure of the (Z)-1,2-di(1,2,3-triazolyl)-alkene **3ba** deserves no special comments, crystallographic data of **4ba** reveal, besides the expected planarity of the bis-triazolopyrazine subunit, that the two phenyl groups face each other with a small dihedral angle of 12° (Figure 2). The introduction of an *i*-Pr substituent at the ortho-position hinders the free rotation of the aryl moieties that results in a broadening of the signals of the methyl groups of **4bc** in ¹H and ¹³C NMR. However, even with a *tert*-butyl substituent, as for **4bn**, it has not been possible to separate atropisomers.

Figure 2. X-ray structures of **3ba** and **4ba** (50% probability ellipsoids)



We then looked into the scope of the mono azidation of bis-boronates **1**. Using the previously described protocol with only one equivalent of sodium azide resulted in poor chemoselectivity (di/mono ≈95/5). In contrast, trimethylsilyl azide underwent the reaction smoothly, affording in good yields the monoborylated compounds **7** and **8** with control of the double bond geometry (Scheme 3).

Scheme 3. Monoazidation of 1-Alkene-1,2-Diboronic Esters and Conversion to the Triazoles **11** and **12**



These species can be engaged in a copper-catalyzed azide-alkyne cycloaddition with 4-ethynylanisole to afford **9** and **10**³³ and further converted to the mono triazole **11** and **12** by Suzuki coupling with 4-bromotoluene (Scheme 3).

CONCLUSION

In this article, we have demonstrated that 1-alkene-1,2-diboronic esters are convenient precursors of the corresponding (*E*)-1-azido or (*Z*)-1,2-diazido alkenes depending upon the azidation reactant. These compounds were then engaged in

CuAAC, without being isolated as regards the bis azides. The wise selection of the catalytic system provides, either 1,2-di-(1,2,3-triazolyl)-alkenes or fused bis-(1,2,3-triazolopyrazines). In the latter case, five bonds are created in the same process with complete conservation of all involved atoms.

EXPERIMENTAL SECTION

General Information. Unless otherwise noted, all solvents and all commercially available chemicals were used without further purification. Air- and water-sensitive reactions were performed in flame-dried glasswares under argon atmosphere. Anhydrous tetrahydrofuran was obtained after distillation over sodium/benzophenone. For oxygen sensitive reaction, when specified, solvent was degassed prior to use by slow bubbling of argon. ¹H NMR spectra (300, 400 or 500 MHz), ¹³C NMR (75, 101 or 126 MHz), ¹¹B (128 MHz) and ¹⁹F (376 MHz) were recorded on Bruker AC 300 and AC 400 spectrometers. Chemical shifts δ are given in ppm and coupling constants J in Hz. Multiplicities are presented as follows: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. High-resolution mass spectra (HRMS) were recorded, either on a Q-TOF Bruker MaXis 4G, a Q-TOF Agilent 6510 or a Thermo Fisher orbitrap Q-Exactive spectrometer (Centre Régional de Mesures Physiques de l'Ouest, Rennes) using positive ion Electron-Spray ionization techniques (ESI+). IR spectrum was recorded on a 100 FT-IR Perkin-Elmer spectrometer. Purifications by silica gel chromatography were carried out on silica 0.060-0.200 mm, 60 Å. Analytical thin layer chromatography was performed on Merck Silica Gel 60 F254 plates. Compounds were visualized by exposure to UV-light (254 nm) or by dipping the plates in a 2.5% solution of p-anisaldehyde in a mixture AcOH/H₂SO₄/EtOH (1/4/95) or in a potassium permanganate solution in a mixture K₂CO₃/(5%) NaOH/Water (20/5/300). Melting points were measured on a Kofler bench Reichert-Jung Heizbank or a melting point apparatus Stuart SMP10 and are uncorrected. Bis-boronates were synthesized according reported procedures: **1a**,³⁴ **1b-e**,³⁵ **1f**,³⁶ **1g**,³⁵ **1h**,³⁶ **1i**.³⁵ Alkynes are commercially available, except 1-(*tert*-butyl)-2-ethynylbenzene **5n** which was prepared according to a reported procedure.³⁷

Safety Considerations. Azides (inorganic and organic) possess toxic properties and are potentially explosive under impact or friction or certain conditions.³⁸ Even if we have never experienced a safety problem with mono and 1,2-diazido alkenes, their manipulation requires special care as:

- Personal protective equipments, including safety glasses and gloves.
- The experiments must be performed behind a suitable fumehood with the sash positioned as low as possible.
- The amount of substance should be kept as small as possible, usually at around 0.5 mmol scale.
- These compounds should never be purified by distillation.

Synthesis of bis-azides 2. To a stirred solution of bispinacolate ester **1a** (0.60 mmol) in MeOH (2 mL), were successively added sodium azide (94 mg, 1.44 mmol) and copper sulfate (187 mg, 0.75 mmol). The reaction mixture was stirred for 8 h at room temperature. The solvent was then distilled under vacuum without going to dryness and without heating. The residue was diluted with water (2 mL) and the aqueous layer was extracted with ethyl acetate (2 × 5 mL). The combined organic extracts were washed with brine (2 mL), filtered through a pad of celite and dried over

MgSO₄. After concentration under vacuum at room temperature, the resulting residue was purified by column chromatography (pentane/CH₂Cl₂ 90/10) to afford **2a**.

(*Z*)-*tert*-Butyl((4,5-diazidopent-4-en-1-yl)oxy)dimethylsilane (**2a**). 98 mg (58%). Colorless oil. ¹H NMR (400 MHz, CDCl₃) δ 5.54 (s, 1H), 3.64 (t, *J* = 5.9 Hz, 2H), 2.24 (td, *J* = 7.6, 1.0 Hz, 2H), 1.72–1.65 (m, 2H), 0.89 (s, 9H), 0.05 (s, 6H). ¹³C NMR (101 MHz, CDCl₃) δ 126.9, 112.5, 61.5, 30.7, 27.5, 26.0, 18.4, -5.2. IR (neat) ν 2955, 2929, 2893, 2080, 1654, 1471, 1387, 1343, 1283, 1256, 1101, 1007, 963, 832, 813, 774 cm⁻¹.

Synthesis of bis-triazoles 3. To a stirred solution of bispinacolate ester **1** (0.6 mmol) in MeOH (3 mL) were added copper sulfate pentahydrate (150 mg, 0.6 mmol) and sodium azide (78 mg, 1.2 mmol). The reaction mixture was then stirred for 8 h at room temperature. After the successive additions of water (2 mL), copper sulfate pentahydrate (150 mg, 0.6 mmol), sodium ascorbate (12 mg, 0.06 mmol) and the alkyne (1.2 mmol), the reaction mixture was stirred for 12 additional hours. Most of the solvent was then evaporated under vacuum and the residue was diluted with water (5 mL). The aqueous layer was extracted with ethyl acetate (3 × 10 mL). The combined organic extracts were washed with brine (5 mL), filtered through a pad of celite and dried over MgSO₄. After concentration under vacuum, the resulting residue was purified by column chromatography to afford **3**.

(*Z*)-1,1'-(*Hex-3-ene-3,4-diyl*)bis(4-phenyl-1*H*-1,2,3-triazole) (**3ba**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 155 mg (70%). White solid, mp = 190–195 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.63–7.61 (m, 4H), 7.34 (s, 2H), 7.37–7.23 (m, 6H), 2.96 (q, *J* = 7.5 Hz, 4H), 1.13 (t, *J* = 7.5 Hz, 6H). ¹³C{¹H} NMR (126 MHz, CDCl₃) δ 148.0, 134.3, 129.7, 128.9, 128.6, 125.9, 121.0, 25.7, 11.8. HRMS (ESI⁺) *m/z* (M+Na)⁺ calcd for C₂₂H₂₂N₆Na 393.1804; found 393.1802.

5,6-Diethyl-1,10-di-*o*-tolylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (**3bb**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 139 mg (58%). White solid, mp = 160–163 °C. ¹H NMR (300 MHz, CDCl₃) δ 7.65–7.62 (m, 2H), 7.24–7.16 (m, 6H), 7.21 (s, 2H), 3.00 (q, *J* = 7.5 Hz, 4H), 2.19 (s, 6H), 1.17 (t, *J* = 7.5 Hz, 6H). ¹³C{¹H} NMR (75 MHz, CDCl₃) δ 147.0, 135.5, 134.4, 131.0, 128.9, 128.9, 128.5, 126.2, 123.2, 25.6, 21.2, 11.8. HRMS (ESI⁺): *m/z* (M+Na)⁺ calcd for C₂₄H₂₆N₆Na 421.2117; found 421.2116.

(*Z*)-1,1'-(*hex-3-ene-3,4-diyl*)bis(4-(2-isopropylphenyl)-1*H*-1,2,3-triazole) (**3bc**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 128 mg (47%). White solid, mp = 107–109 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.34–7.27 (m, 6H), 7.19 (s, 2H), 7.14 (ddd, *J* = 7.6, 6.2, 2.6 Hz, 2H), 2.98 (q, *J* = 7.4 Hz, 4H), 2.98 (sept, *J* = 6.8 Hz, 2H), 1.16 (t, *J* = 7.5 Hz, 6H), 1.05 (d, *J* = 6.8 Hz, 12H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 147.3, 147.1, 134.6, 129.9, 129.0, 128.0, 125.8, 123.4, 29.5, 25.6, 23.9. HRMS (ESI⁺): *m/z* (M+Na)⁺ calcd for C₂₈H₃₄N₆Na 477.2743; found 477.2739.

(*Z*)-2,2'-(*hex-3-ene-3,4-diyl*)bis(1*H*-1,2,3-triazole-1,4-diyl)dipyridine (**3bd**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 75/25). 89 mg (40%). White solid, mp = 172–174 °C. ¹H NMR (300 MHz, CDCl₃) δ 8.47 (ddd, *J* = 4.8, 1.5, 0.8 Hz, 2H), 8.01 (dt, *J* = 7.9, 1.1 Hz, 2H), 7.88 (s, 2H), 7.66 (t, *J* = 7.7, 1.8 Hz, 2H), 7.14 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 2H), 2.90 (q, *J* = 7.5 Hz, 4H), 1.10 (t, *J* = 7.5 Hz, 6H). ¹³C{¹H} NMR (75 MHz, CDCl₃) δ 149.6, 149.5, 148.3, 136.8, 134.6, 123.3, 123.1, 120.4, 25.9, 11.7. HRMS (ESI⁺): *m/z* (M+Na)⁺ calcd for C₂₀H₂₀N₈Na 395.1709; found 395.1698.

(*Z*)-1,1'-(*Hex-3-ene-3,4-diyl*)bis(4-butyl-1*H*-1,2,3-triazole) (**3be**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 119 mg (60%). White solid, mp = 245–250 °C. ¹H NMR (400 MHz, CDCl₃) δ 6.67 (s,

2H), 2.83 (q, *J* = 7.5 Hz, 4H), 2.51 (t, *J* = 7.7 Hz, 4H), 1.45 (pent, *J* = 7.6 Hz, 4H), 1.21 (hex, *J* = 7.3 Hz, 4H), 1.01 (t, *J* = 7.5 Hz, 6H), 0.84 (t, *J* = 7.4 Hz, 6H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 148.3, 134.0, 122.1, 31.4, 25.4, 25.0, 22.2, 13.8, 11.7. HRMS (ESI⁺) *m/z* (M+Na)⁺ calcd for C₁₈H₃₀N₆Na 353.2430; found 353.2422.

(*Z*)-1,1'-(*Hex-1-ene-1,2-diyl*)bis(4-phenyl-1*H*-1,2,3-triazole) (**3ca**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 144 mg (65%). White solid, mp = 188–192 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.85–7.75 (m, 2H), 7.68 (s, 1H), 7.64–7.62 (m, 2H), 7.46–7.40 (m, 3H), 7.39–7.28 (m, 4H), 7.06 (s, 1H), 2.82 (t, *J* = 6.9 Hz, 2H), 1.58–1.39 (m, 4H), 0.96 (t, *J* = 7.2 Hz, 3H). ¹³C{¹H} NMR (126 MHz, CDCl₃) δ 148.8, 148.4, 131.4, 129.52, 129.46, 129.1, 129.0, 128.9, 128.8, 126.1, 126.0, 120.1, 119.5, 118.7, 34.6, 28.7, 22.1, 13.8. HRMS (ESI⁺) *m/z* (M+H)⁺ calcd for C₂₂H₂₃N₆ 371.1984; found 371.1978.

(*Z*)-1,1'-(*Hex-1-ene-1,2-diyl*)bis(4-butyl-1*H*-1,2,3-triazole) (**3ce**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 119 mg (60%). White solid, mp = 248–253 °C. ¹H NMR (500 MHz, CDCl₃) δ 7.31 (s, 1H), 7.06 (s, 1H), 6.32 (s, 1H), 2.71 (t, *J* = 7.5 Hz, 4H), 2.56 (t, *J* = 7.6 Hz, 2H), 1.62 (pent, *J* = 7.7 Hz, 2H), 1.50 (pent, *J* = 7.7 Hz, 2H), 1.46–1.38 (m, 4H), 1.34 (hex, *J* = 7.5 Hz, 2H), 1.27 (hex, *J* = 7.5 Hz, 2H), 0.92 (t, *J* = 7.2 Hz, 3H), 0.92 (t, *J* = 7.3 Hz, 3H), 0.87 (t, *J* = 7.4 Hz, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 149.3, 149.0, 131.0, 121.3, 119.9, 119.6, 34.3, 31.5, 31.3, 28.6, 25.2, 25.1, 22.3, 22.2, 22.0, 13.9, 13.83, 13.80. HRMS (ESI⁺) *m/z* (M+Na)⁺ calcd for C₁₈H₃₀N₆Na 353.2430; found 353.2430.

(*Z*)-1,1'-(*Hex-1-ene-1,2-diyl*)bis(4-(4-chloro-phenyl)-1*H*-1,2,3-triazole) (**3cf**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 173 mg (66%). White solid, mp = 180–185 °C. ¹H NMR (500 MHz, CDCl₃) δ 7.74 (d, *J* = 8.6 Hz, 2H), 7.66 (s, 1H), 7.57 (d, *J* = 8.6 Hz, 2H), 7.41 (s, 1H), 7.39 (d, *J* = 8.6 Hz, 2H), 7.33 (d, *J* = 8.6 Hz, 2H), 7.07 (s, 1H), 2.81 (t, *J* = 7.0 Hz, 2H), 1.54–1.51 (m, 2H), 1.46 (hex, *J* = 7.0 Hz, 2H), 0.96 (t, *J* = 7.2 Hz, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 133.9, 133.5, 121.0, 120.8, 118.0, 115.5, 115.4, 114.1, 114.1, 113.4, 113.3, 108.0, 34.5, 28.7, 22.1, 13.8. HRMS (ESI⁺) *m/z* (M+H)⁺ calcd for C₂₂H₂₁³⁵Cl₂N₆ 439.1205; found 439.1169.

(*Z*)-1,1'-(*Hex-1-ene-1,2-diyl*)bis(4-(4-cyano-phenyl)-1*H*-1,2,3-triazole) (**3cg**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 154 mg (61%). Brown solid, mp = 185–190 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.93 (d, *J* = 8.5 Hz, 2H), 7.84 (s, 1H), 7.78 (d, *J* = 8.5 Hz, 2H), 7.72 (d, *J* = 8.5 Hz, 2H), 7.65 (d, *J* = 8.5 Hz, 2H), 7.42 (s, 1H), 7.34 (s, 1H), 2.84 (t, *J* = 6.9 Hz, 2H), 1.57–1.43 (m, 4H), 0.97 (t, *J* = 7.1 Hz, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 146.9, 146.5, 133.8, 133.0, 132.8, 132.9, 126.4, 126.4, 121.3, 120.3, 119.4, 118.6, 112.5, 112.3, 34.6, 28.6, 22.1, 13.8. HRMS (ESI⁺) *m/z* (M+H)⁺ calcd for C₂₄H₂₁N₈ 421.1889; found 421.1883.

(*Z*)-1,1'-(*Hex-1-ene-1,2-diyl*)bis(4-(2-(trifluoromethyl)phenyl)-1*H*-1,2,3-triazole) (**3ch**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 188 mg (62%). Yellow solid, mp = 115–120 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.98 (d, *J* = 7.8 Hz, 1H), 7.86 (d, *J* = 7.8 Hz, 1H), 7.73 (d, *J* = 7.9 Hz, 1H), 7.69 (s, 1H), 7.68 (d, *J* = 7.8 Hz, 1H), 7.64 (t, *J* = 7.6 Hz, 1H), 7.60 (t, *J* = 7.6 Hz, 1H), 7.50 (t, *J* = 7.7 Hz, 1H), 7.47 (s, 1H), 7.46 (t, *J* = 7.7 Hz, 1H), 7.11 (s, 1H), 2.84 (t, *J* = 6.8 Hz, 2H), 1.59–1.40 (m, 4H), 0.96 (t, *J* = 7.1 Hz, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 145.2, 144.9, 132.2, 132.1, 131.9, 131.8, 131.6, 128.9, 128.8, 128.5, 128.5, 127.65 (q, *J* = 30.4 Hz), 127.54 (q, *J* = 30.7 Hz), 126.3 (q, *J* = 2.5 Hz), 126.2 (q, *J* = 2.4 Hz), 124.3 (q, *J* = 273.4 Hz), 124.3 (q, *J* = 273.5 Hz), 123.4 (q, *J* = 5.3 Hz), 122.3 (q, *J* =

5.4 Hz), 119.6, 34.6, 28.5, 22.0, 13.8. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3): δ -58.7, -58.9. HRMS (ESI^+) m/z ($\text{M}+\text{Na}$) $^+$ calcd for $\text{C}_{24}\text{H}_{20}^{19}\text{F}_6\text{N}_6\text{Na}$ 529.1545; found 529.1545.

(*Z*)-1,1'-(hex-1-ene-1,2-diyl)bis(4-(4-methoxy-phenyl)-1*H*-1,2,3-triazole) (**3ci**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 163 mg (63%). White solid, mp = 114-119 $^\circ\text{C}$. ^1H NMR (500 MHz, CDCl_3) δ 7.73 (d, $J = 8.8$ Hz, 2H), 7.57 (s, 1H), 7.56 (d, $J = 8.7$ Hz, 2H), 7.41 (s, 1H), 6.95 (d, $J = 8.8$ Hz, 2H), 6.93 (s, 1H), 6.87 (d, $J = 8.8$ Hz, 2H), 3.84 (s, 3H), 3.79 (s, 3H), 2.79 (t, $J = 7.1$ Hz, 2H), 1.59-1.49 (m, 2H), 1.45 (hex, $J = 6.9$ Hz, 2H), 0.95 (t, $J = 7.2$ Hz, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 160.2, 160.1, 148.6, 148.3, 130.9, 127.4, 127.3, 122.2, 119.5, 119.2, 117.7, 114.5, 114.4, 55.5, 55.4, 34.5, 28.7, 22.1, 13.8. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{24}\text{H}_{27}\text{N}_6\text{O}_2$ 431.2190; found 431.2191.

(*Z*)-1,1'-(hex-1-ene-1,2-diyl)bis(4-(4-fluoro-phenyl)-1*H*-1,2,3-triazole) (**3cj**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 144 mg (59%). White solid, mp = 176-180 $^\circ\text{C}$. ^1H NMR (500 MHz, CDCl_3) δ 7.79-7.76 (m, 2H), 7.63 (s, 1H), 7.63-7.60 (m, 2H), 7.42 (iis, 1H), 7.14-7.10 (m, 2H), 7.06-7.03 (m, 2H), 7.03 (s, 1H), 2.81 (t, $J = 7.0$ Hz, 2H), 1.56-1.50 (m, 2H), 1.46 (hex, $J = 7.0$ Hz, 2H), 0.96 (t, $J = 7.2$ Hz, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 163.2 (d, $J = 248.3$ Hz), 163.1 (d, $J = 248.3$ Hz), 147.9, 147.6, 131.7, 127.8 (d, $J = 6.8$ Hz), 127.8 (d, $J = 6.8$ Hz), 125.7 (s), 119.8, 119.5, 118.5, 116.2 (d, $J = 21.6$ Hz), 116.0 (d, $J = 21.6$ Hz), 34.6, 28.7, 22.1, 13.8. ^{19}F NMR (376 MHz, CDCl_3) δ -112.2, -112.5. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{22}\text{H}_{21}\text{N}_6^{19}\text{F}_2$ 407.1790; found 407.1792.

(*Z*)-1,1'-(Hex-1-ene-1,2-diyl)bis(4-(4-bromophenyl)-1*H*-1,2,3-triazole) (**3ck**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 205 mg (65%). Yellow solid, mp = 194-198 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.67 (d, $J = 8.4$ Hz, 2H), 7.67 (s, 1H), 7.56 (d, $J = 8.5$ Hz, 2H), 7.51 (d, $J = 8.7$ Hz, 2H), 7.48 (d, $J = 8.7$ Hz, 2H), 7.41 (s, 1H), 7.07 (s, 1H), 2.81 (t, $J = 7.1$ Hz, 2H), 1.56-1.41 (m, 4H), 0.96 (t, $J = 7.1$ Hz, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 147.8, 147.4, 132.4, 132.2, 131.9, 128.4, 127.5, 127.5, 123.0, 122.9, 120.1, 119.5, 118.9, 34.6, 28.7, 22.1, 13.8. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{22}\text{H}_{21}\text{N}_6^{79}\text{Br}_2$ 527.0194; found 527.0203.

(*Z*)-1,1'-(Hex-1-ene-1,2-diyl)bis(4-(cyclohexylmethyl)-1*H*-1,2,3-triazole) (**3cl**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 143 mg (58%). White solid, mp = 115-120 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.31 (s, 1H), 7.04 (s, 1H), 6.30 (s, 1H), 2.73 (t, $J = 6.8$ Hz, 2H), 2.58 (d, $J = 6.6$ Hz, 2H), 2.43 (d, $J = 6.9$ Hz, 2H), 1.71-1.56 (m, 12H), 1.53-1.36 (m, 6H), 1.21-1.08 (m, 4H), 0.93 (t, $J = 7.1$ Hz, 3H), 0.90-0.80 (m, 4H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 147.8, 147.5, 131.0, 121.9, 120.5, 119.6, 38.0, 37.9, 34.3, 33.3, 33.1, 33.0, 29.8, 28.6, 26.5, 26.5, 26.3, 26.2, 22.0, 13.8. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{24}\text{H}_{39}\text{N}_6$ 411.3230; found 411.3226.

(*Z*)-1,1'-(3-Cyclohexylprop-1-ene-1,2-diyl)bis(4-(2-(trifluoromethyl)phenyl)-1*H*-1,2,3-triazole) (**3dh**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 2/8$). 197 mg (60%). Pale yellow solid, mp = 116-120 $^\circ\text{C}$. ^1H NMR (500 MHz, CDCl_3) δ 7.98 (d, $J = 7.8$ Hz, 1H), 7.86 (d, $J = 7.8$ Hz, 1H), 7.74 (d, $J = 7.9$ Hz, 1H), 7.69 (s, 1H), 7.68 (d, $J = 7.7$ Hz, 1H), 7.65 (t, $J = 7.7$ Hz, 1H), 7.60 (t, $J = 7.7$ Hz, 1H), 7.51 (t, $J = 7.7$ Hz, 1H), 7.46 (t, $J = 7.7$ Hz, 1H), 7.44 (s, 1H), 7.12 (s, 1H), 2.70 (d, $J = 7.0$ Hz, 2H), 1.83-1.64 (m, 6H), 1.36-1.29 (m, 1H), 1.20-1.18 (m, 2H), 1.07-1.00 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 145.2, 144.9, 132.2, 132.1, 131.9, 131.8, 130.2, 128.9, 128.8, 128.5, 128.5, 127.67 (q, $J = 30.4$ Hz), 127.57 (q, $J = 30.6$ Hz), 126.31 (q, $J = 3.3$ Hz), 126.24 (q, $J = 3.2$ Hz), 124.1 (q, $J = 273.5$ Hz), 124.0 (q, $J = 273.6$ Hz),

123.4 (q, $J = 5.4$ Hz), 122.1 (q, $J = 5.4$ Hz), 120.1, 42.5, 34.9, 32.9, 26.2, 26.0. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3): δ -58.7, -58.9. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{27}\text{H}_{25}\text{N}_6^{19}\text{F}_6$ 547.2039; found 547.2036.

(*Z*)-1,1'-(3-Cyclohexylprop-1-ene-1,2-diyl)bis(4-(4-methoxyphenyl)-1*H*-1,2,3-triazole) (**3di**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 4/6$). 178 mg (63%). White solid, mp = 127-130 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.73 (d, $J = 8.8$ Hz, 2H), 7.56 (s, 1H), 7.56 (d, $J = 8.7$ Hz, 2H), 7.37 (s, 1H), 6.97 (s, 1H), 6.95 (d, $J = 9.0$ Hz, 2H), 6.94 (s, 1H), 6.87 (d, $J = 8.7$ Hz, 1H), 3.84 (s, 3H), 3.80 (s, 3H), 2.66 (d, $J = 7.0$ Hz, 2H), 1.84-1.67 (m, 6H), 1.41-1.35 (m, 1H), 1.20-1.17 (m, 2H), 1.07-0.98 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 160.2, 160.1, 148.7, 148.3, 129.6, 127.4, 127.4, 122.3, 120.1, 119.1, 117.8, 114.6, 114.4, 55.5, 55.4, 42.5, 34.9, 33.0, 26.3, 26.0, 25.0. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{27}\text{H}_{31}\text{N}_6\text{O}_2$ 471.2503; found 471.2505.

(*Z*)-1,1'-(3-Cyclohexylprop-1-ene-1,2-diyl)bis(4-(4-fluorophenyl)-1*H*-1,2,3-triazole) (**3dj**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 163 mg (61%). White solid, mp = 181-185 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.81-7.76 (m, 2H), 7.64-7.60 (m, 2H), 7.63 (s, 1H), 7.38 (s, 1H), 7.15-7.09 (m, 2H), 7.07-7.02 (m, 2H), 7.05 (s, 1H), 2.68 (d, $J = 7.1$ Hz, 2H), 1.88-1.70 (m, 6H), 1.42-1.33 (m, 1H), 1.26-1.15 (m, 2H), 1.08-0.99 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 163.2 (d, $J = 248.6$ Hz), 163.1 (d, $J = 248.4$ Hz), 147.9, 147.5, 130.2, 127.84 (d, $J = 8.3$ Hz), 127.79 (d, $J = 8.0$ Hz), 125.73 (d, $J = 2.6$ Hz), 125.71 (d, $J = 2.9$ Hz), 120.1, 119.8, 118.6, 116.2 (d, $J = 21.9$ Hz), 116.1 (d, $J = 21.8$ Hz), 42.4, 34.9, 32.9, 26.2, 26.0. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3): δ -112.2, -112.5. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{25}\text{H}_{25}^{19}\text{F}_2\text{N}_6$ 447.2109; found 447.2115.

(*Z*)-1,1'-(3-Cyclohexylprop-1-ene-1,2-diyl)bis(4-(*p*-tolyl)-1*H*-1,2,3-triazole) (**3dm**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 176 mg (67%). White solid, mp = 213-218 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.69 (d, $J = 8.1$ Hz, 2H), 7.61 (s, 1H), 7.52 (d, $J = 8.1$ Hz, 2H), 7.38 (s, 1H), 7.23 (d, $J = 8.0$ Hz, 2H), 7.15 (d, $J = 7.9$ Hz, 2H), 6.99 (s, 1H), 2.67 (d, $J = 6.8$ Hz, 2H), 2.38 (s, 3H), 2.33 (s, 3H), 1.86-1.80 (m, 2H), 1.86-1.60 (m, 4H), 1.41-1.36 (m, 1H), 1.23-1.15ii (m, 2H), 1.07-0.98 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 148.9, 148.5, 138.9, 138.7, 129.8, 129.7, 126.7, 126.0, 125.9, 120.1, 119.6, 118.3, 42.5, 34.9, 32.9, 26.3, 26.0, 21.5, 21.4. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{27}\text{H}_{31}\text{N}_6$ 439.2604; found 439.2603.

(*Z*)-1,1'-(3-Phenylprop-1-ene-1,2-diyl)bis(4-(2-(trifluoromethyl)phenyl)-1*H*-1,2,3-triazole) (**3eh**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 3/7$). 207 mg (64%). White solid, mp = 256-260 $^\circ\text{C}$. ^1H NMR (500 MHz, CDCl_3) δ 7.90 (d, $J = 7.8$ Hz, 1H), 7.84 (d, $J = 7.8$ Hz, 1H), 7.69 (d, $J = 8.7$ Hz, 1H), 7.67 (d, $J = 8.6$ Hz, 1H), 7.62 (t, $J = 7.4$ Hz, 1H), 7.59 (t, $J = 7.6$ Hz, 1H), 7.50 (s, 1H), 7.48 (t, $J = 8.7$ Hz, 1H), 7.46 (t, $J = 8.1$ Hz, 1H), 7.42 (s, 1H), 7.38-7.29 (m, 3H), 7.25 (d, $J = 8.1$ Hz, 1H), 7.07 (s, 1H), 4.11 (s, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 145.1, 145.0, 134.1, 132.1 (2C), 131.9, 131.8, 130.4, 129.35, 129.27, 128.8, 128.4, 128.3, 128.1, 127.63 (q, $J = 30.7$ Hz), 127.61 (q, $J = 30.5$ Hz), 126.3 (q, $J = 4.7$ Hz), 126.2 (q, $J = 4.3$ Hz), 123.92 (q, $J = 273.7$ Hz), 123.91 (q, $J = 273.9$ Hz), 123.7 (q, $J = 4.9$ Hz), 122.0 (q, $J = 4.9$ Hz), 121.9, 120.8, 41.3. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3): δ -58.85, -58.9. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{27}\text{H}_{19}\text{N}_6^{19}\text{F}_6$ 541.1569; found 541.1568.

(*Z*)-1,1'-(3-Phenylprop-1-ene-1,2-diyl)bis(4-(4-methoxyphenyl)-1*H*-1,2,3-triazole) (**3ei**). The crude product was purified using silica gel column chromatography ($\text{EtOAc}/\text{hexanes} = 5/5$). 173 mg (62%). White solid, mp = 165-170 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.66-7.62 (m, 2H), 7.56-7.52 (m, 2H), 7.41

(s, 1H), 7.37-7.31 (m, 3H), 7.30 (s, 1H), 7.25 (d, $J = 7.8$ Hz, 2H), 6.94-6.90 (m, 2H), 6.90 (s, 1H), 6.88-6.84 (m, 2H), 4.09 (s, 2H), 3.82 (s, 3H), 3.79 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 160.2, 160.1, 148.5, 148.4, 134.5, 129.9, 129.3, 128.0, 127.4, 122.2, 122.0, 120.8, 119.5, 117.6, 114.5, 114.4, 55.5, 55.4, 41.1. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{27}\text{H}_{25}\text{N}_6\text{O}_2$ 465.2033; found 465.2037.

(*Z*)-1,1'-(3-Phenylprop-1-ene-1,2-diyl)bis(4-(4-fluorophenyl)-1*H*-1,2,3-triazole) (**3ej**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 158 mg (60%). Yellow solid, mp = 194-198 °C. ^1H NMR (400 MHz, CDCl_3) δ 7.77-7.66 (m, 2H), 7.61-7.58 (m, 2H), 7.42 (s, 1H), 7.36 (s, 1H), 7.36-7.31 (m, 3H), 7.28-7.25 (m, 2H), 7.09 (t, $J = 8.7$ Hz, 2H), 7.03 (t, $J = 8.7$ Hz, 2H), 7.00 (s, 1H), 4.10 (s, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 163.1 (d, $J = 248.7$ Hz), 163.1 (d, $J = 248.6$ Hz), 147.7, 147.6, 134.2, 130.5, 129.4, 129.3, 128.8, 128.63, 128.58, 128.1, 127.84, 127.75, 125.7 (d, $J = 3.1$ Hz), 125.6 (d, $J = 2.9$ Hz), 120.7, 120.2, 118.4, 116.2 (d, $J = 21.9$ Hz), 116.1 (d, $J = 21.8$ Hz), 41.1. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3) δ -112.2, -112.3. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{25}\text{H}_{19}\text{N}_6^{19}\text{F}_2$ 441.1639; found 441.1637.

Synthesis of fused bis-(1,2,3-triazolo)-pyrazines 4. To a stirred solution of bispinacolate ester **1** (0.6 mmol) in MeOH (3 mL) were successively added copper sulfate pentahydrate (150 mg, 0.6 mmol) and sodium azide (78 mg, 1.19 mmol). The reaction mixture was stirred for 8 h at room temperature. Cs_2CO_3 (48 mg, 0.14 mmol) and alkyne (1.2 mmol) were then added and the reaction mixture was stirred for 12 h at rt. After completion of the reaction, most of the solvent was evaporated under vacuum. After addition of water (5 mL), the aqueous layer was extracted with ethyl acetate (2 \times 10 mL). The combined organic extracts were washed with brine (5 mL), filtered through a pad of celite, dried over MgSO_4 and concentrated under vacuum. The resulting residue was purified by column chromatography on silica gel (Hexane /AcOEt 8/2 to 6/4) to afford **4**. The reaction was also carried out on a 3 mmol scale for **4gr**. From 952 mg (3 mmol) of **3g** and 396 mg (6 mmol) of **5r** was obtained 617 mg (73%) of **4gr**.

5-(3-((*Tert*-butyldimethylsilyl)oxy)propyl)-1,10-diphenylbis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4aa**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 218 mg (75%). White solid, mp = 153-158 °C. ^1H NMR (500 MHz, CDCl_3) δ 8.04 (s, 1H), 7.19-7.11 (m, 6H), 6.97-6.92 (m, 4H), 3.84 (t, $J = 5.7$ Hz, 2H), 3.39 (t, $J = 7.2$ Hz, 2H), 2.24-2.18 (m, 2H), 0.91 (s, 9H), 0.09 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 142.8, 142.2, 129.5, 129.4, 128.6, 128.5, 128.4, 128.3, 128.2, 127.6, 121.3, 120.7, 110.7, 61.7, 29.5, 25.9, 25.3, 18.3, -5.2. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{27}\text{H}_{33}\text{N}_6\text{O}_2\text{Si}$ 485.2486; found 485.2485.

5,6-Diethyl-1,10-diphenylbis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4ba**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 181 mg (82%). White solid, mp = 220-223 °C. ^1H NMR (400 MHz, CDCl_3) δ 7.19-7.10 (m, 6H), 6.94 (t, $J = 7.7$ Hz, 4H), 3.41 (q, $J = 7.4$ Hz, 4H), 1.54 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 142.4, 129.8, 128.5, 128.4, 127.6, 125.4, 120.6, 20.2, 12.7. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{22}\text{H}_{21}\text{N}_6$ 369.1831; found 369.1828.

5,6-Diethyl-1,10-di-*o*-tolylbis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bb**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 152 mg (64%). White solid, mp = 188-190 °C. ^1H NMR (300 MHz, CDCl_3) δ 7.00 (td, $J = 7.5$, 1.5 Hz, 2H), 6.89 (dd, $J = 7.6$, 1.4 Hz, 2H), 6.82-6.73 (m, 4H), 3.41 (q, $J = 7.4$ Hz, 4H), 1.99 (s, 6H), 1.56 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 141.8, 136.8, 130.0, 129.6, 129.1, 129.1, 125.3, 125.1, 121.5, 20.3, 20.2, 12.8. HRMS (ESI^+): m/z ($\text{M}+\text{Na}$) $^+$ calcd for $\text{C}_{24}\text{H}_{24}\text{N}_6\text{Na}$ 419.1960; found 419.1956.

5,6-Diethyl-1,10-bis(2-isopropylphenyl)bis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bc**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 149 mg (55%). Colorless oil. ^1H NMR (300 MHz, CDCl_3) δ 7.25 (d, $J = 7.9$ Hz, 2H), 7.08 (t, $J = 7.6$ Hz, 2H), 6.51 (d, $J = 7.3$ Hz, 2H), 6.43 (t, $J = 7.4$ Hz, 2H), 3.44 (q, $J = 7.4$ Hz, 4H), 3.26 (sept, $J = 6.9$ Hz, 2H), 1.59 (t, $J = 7.4$ Hz, 6H), 1.28 (br s, 12H). $^{13}\text{C}\{^1\text{H}\}$ NMR (75 MHz, CDCl_3) δ 147.2, 141.7, 130.5, 129.3, 127.9, 125.2, 125.2, 125.1, 121.6, 29.9, 24.2 (br), 20.3, 12.8. HRMS (ESI^+) m/z ($\text{M}+\text{Na}$) $^+$ calcd for $\text{C}_{28}\text{H}_{32}\text{N}_6\text{Na}$ 475.2586; found 475.2584.

5,6-diethyl-1,10-di(pyridin-2-yl)bis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bd**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 75:25). 113 mg (51%). Colorless oil. ^1H NMR (300 MHz, CDCl_3) δ 8.03 (dt, $J = 7.8$, 1.1 Hz, 2H), 7.74 (td, $J = 7.7$, 1.8 Hz, 2H), 7.59 (dt, $J = 5.2$, 1.3 Hz, 2H), 7.02 (ddd, $J = 7.6$, 4.8, 1.2 Hz, 2H), 3.41 (q, $J = 7.4$ Hz, 4H), 1.49 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (75 MHz, CDCl_3) δ 150.8, 148.2, 143.1, 136.1, 125.7, 123.2, 122.7, 122.0, 20.2, 12.8. HRMS (ESI^+) m/z ($\text{M}+\text{Na}$) $^+$ calcd for $\text{C}_{20}\text{H}_{18}\text{N}_8\text{Na}$ 393.1552; found 393.1550.

1,10-dibutyl-5,6-diethylbis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4be**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 148 mg (75%). White solid, mp = 121-125 °C. ^1H NMR (500 MHz, CDCl_3) δ 3.29 (q, $J = 7.4$ Hz, 4H), 3.17 (t, $J = 7.9$ Hz, 2H), 3.17 (t, $J = 7.9$ Hz, 2H), 1.90-1.81 (m, 4H), 1.51 (hex, $J = 7.4$ Hz, 4H), 1.45 (t, $J = 7.5$ Hz, 6H), 1.00 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 141.6, 124.7, 121.2, 32.31, 29.7, 26.5, 22.6, 19.9, 13.9, 12.6. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{18}\text{H}_{29}\text{N}_6$ 329.2461; found 329.2454.

1,10-Bis(4-chlorophenyl)-5,6-diethylbis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bf**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 175 mg (69%). Yellow solid, mp = 246-250 °C. ^1H NMR (500 MHz, CDCl_3) δ 7.07 (d, $J = 8.4$ Hz, 4H), 7.01 (d, $J = 8.5$ Hz, 4H), 3.40 (q, $J = 7.5$ Hz, 4H), 1.53 (t, $J = 7.5$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 141.1, 135.3, 129.7, 128.2, 127.9, 125.5, 120.6, 20.1, 12.6. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{22}\text{H}_{19}\text{Cl}_2\text{N}_6$ 437.1053; found 437.1048.

5,6-Diethyl-1,10-bis(4-methoxyphenyl)bis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bi**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 179 mg (70%). White solid, mp = 185-188 °C. ^1H NMR (400 MHz, CDCl_3) δ 7.05 (d, $J = 8.7$ Hz, 4H), 6.50 (d, $J = 8.7$ Hz, 4H), 3.75 (s, 6H), 3.38 (q, $J = 7.4$ Hz, 4H), 1.53 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 159.9, 142.0, 129.7, 125.2, 122.2, 120.5, 113.0, 55.0, 20.1, 12.7. HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{24}\text{H}_{25}\text{N}_6\text{O}_2$ 429.2039; found 429.2032.

5,6-Diethyl-1,10-bis(4-fluorophenyl)bis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bj**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 145 mg (60%). White solid, mp = 229-232 °C. ^1H NMR (400 MHz, CDCl_3) δ 7.13 (dd, $J = 8.6$, 5.4 Hz, 4H), 6.72 (t, $J = 8.6$ Hz, 4H), 3.40 (q, $J = 7.4$ Hz, 4H), 1.54 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 163.3 (d, $J = 249.5$ Hz), 141.2, 130.3 (d, $J = 8.4$ Hz), 125.9 (d, $J = 2.7$ Hz), 125.4, 120.5, 114.8 (d, $J = 21.9$ Hz), 20.1, 12.6. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3) δ -112.55 (s). HRMS (ESI^+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{22}\text{H}_{19}^{19}\text{F}_2\text{N}_6$ 405.1646; found 405.1639.

5,6-Diethyl-1,10-di-*p*-tolylbis([1,2,3]triazolo)[1,5-*a:5'*,1'-*c*]pyrazine (**4bm**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 154 mg (65%). White solid, mp = 255-258 °C. ^1H NMR (500 MHz, CDCl_3) δ 7.02 (d, $J = 8.1$ Hz, 4H), 6.75 (d, $J = 7.8$ Hz, 4H), 3.39 (q, $J = 7.5$ Hz, 4H), 2.29 (s, 6H), 1.53 (t, $J = 7.5$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR

(101 MHz, CDCl₃) δ 142.4, 138.2, 128.3, 128.2, 127.0, 125.2, 120.6, 21.3, 20.1, 12.7. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₂₄H₂₅N₆ 397.2144; found 397.2141.

1,10-bis(2-(tert-butyl)phenyl)-5,6-diethylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4bn). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 94 mg (48%). Colorless oil. ¹H NMR (300 MHz, CDCl₃) δ 7.34 (d, *J* = 8.1 Hz, 2H), 7.00 (t, *J* = 8.0 Hz, 2H), 6.61 (d, *J* = 7.4 Hz, 2H), 6.52 (t, *J* = 7.4 Hz, 2H), 3.42 (q, *J* = 7.4 Hz, 4H), 1.56 (t, *J* = 7.4 Hz, 6H), 1.26 (s, 18H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 153.3, 136.3, 129.2, 125.8, 125.8, 120.4, 84.1, 80.0, 36.1, 30.4. HRMS (ESI⁺) m/z (M+Na)⁺ calcd for C₃₀H₃₆N₆Na 503.2899; found 503.2893.

1,10-Dicyclohexyl-5,6-diethylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4bo). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 143 mg (63%). Yellow solid, mp = 129–133 °C. ¹H NMR (400 MHz, CDCl₃) δ 3.28 (q, *J* = 7.4 Hz, 4H), 3.22–3.14 (m, 2H), 2.05–1.92 (m, 12H), 1.89–1.81 (m, 2H), 1.56–1.38 (m, 6H), 1.44 (t, *J* = 7.4 Hz, 6H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 146.1, 124.6, 120.5, 36.2, 33.2, 26.7, 25.9, 20.0, 12.6. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₂₂H₃₃N₆ 381.2767; found 381.2765.

1,10-Dibenzyl-5,6-diethylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4bp). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 154 mg (65%). White solid, mp = 170–175 °C. ¹H NMR (500 MHz, CDCl₃) δ 7.27–7.18 (m, 6H), 7.08–7.08 (m, 4H), 4.37 (s, 4H), 3.34 (q, *J* = 7.4 Hz, 4H), 1.48 (t, *J* = 7.4 Hz, 6H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 139.3, 138.4, 128.7, 127.9, 126.7, 125.1, 121.8, 31.7, 20.1, 12.6. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₂₄H₂₅N₆ 397.2142; found 397.2141.

1,10-Bis(3-chloropropyl)-5,6-diethylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4bq). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 168 mg (76%). White solid, mp = 176–180 °C. ¹H NMR (500 MHz, CDCl₃) δ 3.76 (t, *J* = 6.2 Hz, 4H), 3.42 (t, *J* = 6.4 Hz, 4H), 3.31 (q, *J* = 7.5 Hz, 4H), 2.44 (quint, *J* = 6.3 Hz, 4H), 1.45 (t, *J* = 7.5 Hz, 6H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 139.8, 124.9, 121.4, 44.3, 31.7, 23.9, 20.4, 12.6. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₁₆H₂₃³⁵Cl₂N₆ 369.1361; found 369.1359.

1,5,10-Tributylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4ce). 122 mg (62%). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). White solid, mp = 121–125 °C. ¹H NMR (500 MHz, CDCl₃) δ 7.87 (t, *J* = 1.0 Hz, 1H), 3.21–3.13 (m, 6H), 1.98–1.77 (m, 6H), 1.58–1.46 (m, 6H), 1.02 (t, *J* = 7.4 Hz, 3H), 1.00 (t, *J* = 7.4 Hz, 3H), 0.99 (t, *J* = 7.4 Hz, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 142.1, 141.5, 127.9, 122.0, 121.3, 110.0, 32.2, 28.4, 27.9, 26.4, 26.3, 22.5, 22.3, 13.8, 13.7. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₁₈H₂₉N₆ 329.2461; found 329.2454.

5-Butyl-1,10-bis(4-methoxyphenyl)bis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4ci). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 180 mg (70%). White solid, mp = 170–175 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.98 (t, *J* = 1.0 Hz, 1H), 7.08–7.03 (m, 4H), 6.53–6.48 (m, 4H), 3.75 (s, 6H), 3.28 (td, *J* = 7.7, 0.8 Hz, 2H), 1.97 (quint, *J* = 7.7 Hz, 2H), 1.61–1.56 (m, 2H), 1.05 (t, *J* = 7.4 Hz, 3H). ¹³C{¹H} NMR (126 MHz, CDCl₃) δ 160.1, 160.0, 142.5, 141.9, 129.8, 129.7, 128.4, 121.9, 121.8, 121.2, 120.6, 113.1, 110.3, 55.0, 28.5, 28.1, 22.3, 13.8. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₂₄H₂₅N₆O₂ 429.2039; found 429.2032.

5-Cyclohexyl-1,10-bis(4-methoxyphenyl)bis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4fi). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 160 mg (59%). White solid, mp = 155–158 °C. ¹H NMR (300 MHz, CDCl₃) δ 7.96 (s, 1H), 7.08–7.02 (m, 4H), 6.50 (d, *J* = 8.2 Hz, 4H), 3.75 (s, 6H), 3.70–3.57 (m,

1H), 2.44–2.34 (m, 2H), 2.04–1.84 (m, 2H), 1.70–1.45 (m, 5H), 1.47–1.33 (m, 1H). ¹³C{¹H} NMR (126 MHz, CDCl₃) δ 160.1, 160.0, 142.3, 141.8, 133.3, 129.7, 129.7, 122.0, 121.8, 121.2, 120.4, 113.0, 109.2, 55.0, 36.8, 31.1, 26.1, 26.0. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₂₆H₂₇N₆O₂ 455.2196; found 455.2192.

5-Cyclohexyl-1,10-dicyclopropylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4fr). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 145 mg (75%). White solid, mp = 183–188 °C. ¹H NMR (300 MHz, CDCl₃) δ 7.82 (s, 1H), 3.55–3.45 (m, 1H), 2.63–2.48 (m, 2H), 2.33–2.24 (m, 2H), 2.01–1.77 (m, 4H), 1.66–1.45 (m, 4H), 1.32–1.23 (m, 4H), 1.17–1.04 (m, 4H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 143.1, 142.5, 132.8, 123.0, 122.3, 108.9, 36.6, 31.0, 26.1, 26.0, 8.2, 8.1, 7.5, 7.4. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₁₈H₂₃N₆ 323.1984; found 323.1982.

1,5,10-Tricyclopropylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4gr). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 128 mg (76%). White solid, mp = 230–235 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.73 (d, *J* = 1.2 Hz, 1H), 2.60–2.50 (m, 3H), 1.32–1.24 (m, 6H), 1.15–1.08 (m, 4H), 0.96–0.91 (m, 2H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 143.4, 142.7, 129.8, 123.0, 122.4, 109.0, 9.1, 8.3, 8.2, 7.5, 7.4, 6.7. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₁₅H₁₇N₆ 281.1515; found 281.1513.

1,5,10-Tris(3-chloropropyl)bis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4hq). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 170 mg (73%). White solid, mp = 165–169 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.99 (s, 1H), 3.74 (t, *J* = 5.9 Hz, 2H), 3.73 (t, *J* = 5.9 Hz, 2H), 3.68 (t, *J* = 6.1 Hz, 2H), 3.40 (quint, *J* = 7.1 Hz, 6H), 2.47–2.38 (m, 6H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 140.5, 139.9, 126.1, 122.3, 121.6, 111.0, 44.2, 43.6, 31.6, 29.0, 25.8, 23.9, 23.8. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₁₅H₂₀³⁵Cl₃N₆ 389.0817; found 389.0815.

5-(3-Chloropropyl)-1,10-dicyclopropylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4hr). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 138 mg (73%). White solid, mp = 158–163 °C. ¹H NMR (500 MHz, CDCl₃) δ 7.92 (s, 1H), 3.66 (t, *J* = 6.1 Hz, 2H), 3.35 (t, *J* = 7.2 Hz, 2H), 2.55 (qt, *J* = 8.4, 5.0 Hz, 2H), 2.40 (td, *J* = 12.7, 6.3 Hz, 2H), 1.32–1.25 (m, 4H), 1.16–1.09 (m, 4H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 143.4, 142.8, 125.8, 123.1, 122.6, 110.9, 43.6, 29.1, 25.8, 8.3, 8.2, 7.5, 7.4. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₁₅H₁₈³⁵ClN₆ 317.1281; found 317.1271.

5-Methyl-1,6,10-triphenylbis([1,2,3]triazolo)[1,5-*a*:5',1'-*c*]pyrazine (4ia). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 7/3). 164 mg (68%). White solid, mp = 210–215 °C. ¹H NMR (500 MHz, CDCl₃) δ 7.69–7.62 (m, 5H), 7.21–7.11 (m, 6H), 6.98–6.92 (m, 4H), 2.81 (s, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 142.7, 142.3, 131.0, 130.5, 129.71, 129.67, 129.1, 128.6, 128.5, 128.4, 128.1, 127.7, 127.6, 124.0, 122.0, 120.82, 120.79, 13.9. HRMS (ESI⁺) m/z (M+H)⁺ calcd for C₂₅H₁₉N₆ 403.1671; found 403.1667.

Monoazidation of bisboronates. To a stirred solution of boronic ester **1** (0.60 mmol) in MeOH (2 mL), were successively added TMSN₃ (69 mg, 78 μ L, 0.60 mmol) and copper sulfate pentahydrate (92 mg, 0.37 mmol) at room temperature. After stirring for 12 h, the reaction mixture was diluted with water (5 mL) and extracted with ethyl acetate (2 x 10 mL). The combined organic extracts were washed with brine (5 mL), dried over MgSO₄ and concentrated under vacuum. The resulting residue was purified by column chromatography to afford **7** or **8**.

(E)-2-(1-Azidohex-1-en-2-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (7). The crude product was purified using silica gel column chromatography (Hexane /AcOEt 9.5/0.5). 108 mg

(72%). Colorless oil. ^1H NMR (400 MHz, CDCl_3) δ 6.55 (s, 1H), 2.08 (t, J = 6.8 Hz, 2H), 1.38-1.28 (m, 4H), 1.29 (s, 12H), 0.88 (t, J = 7.1 Hz, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 136.7, 83.5, 33.0, 32.5, 24.9, 22.4, 14.1. The carbon α to boron was not observed. $^{11}\text{B}\{^1\text{H}\}$ NMR (128 MHz, CDCl_3) δ 29.8 HRMS (ESI+) m/z ($\text{M}-\text{N}_2+\text{H}$) $^+$ calcd for $\text{C}_{12}\text{H}_{23}^{11}\text{BNO}_2$ 224.1822; found 224.1816.

(*E*)-2-(1-Azido-3-cyclohexylprop-1-en-2-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**8**). The crude product was purified using silica gel column chromatography (Hexane /AcOEt 9.5/0.5). 120 mg (69%). Colorless oil. ^1H NMR (400 MHz, CDCl_3) δ 6.50 (s, 1H), 1.97 (d, J = 6.6 Hz, 2H), 1.75-1.57 (m, 6H), 1.28 (s, 12H), 1.18-1.09 (m, 3H), 0.93-0.75 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 137.1, 83.5, 40.9, 38.6, 33.2, 26.7, 26.5, 24.8. The carbon α to boron was not observed. $^{11}\text{B}\{^1\text{H}\}$ NMR (128 MHz, CDCl_3) δ 29.9. HRMS (ESI+) m/z ($\text{M}-\text{N}_2+\text{H}$) $^+$ calcd for $\text{C}_{15}\text{H}_{27}^{11}\text{BNO}_2$ 264.2135; found 264.2129.

Access to triazoles 9 and 10. To a stirred solution of mono-azide **7** or **8** (0.40 mmol) in MeOH (2 mL) and water (2 mL), were added copper sulfate pentahydrate (60 mg, 0.24 mmol), sodium ascorbate (4 mg, 0.02 mmol) and 1-ethynyl-4-methoxybenzene (53 mg, 52 μL , 0.40 mmol). The reaction mixture was stirred for 12 h at room temperature. The solvent was evaporated under vacuum. Water (5 mL) was then added. The aqueous layer was extracted with ethyl acetate (2 \times 10 mL). The combined organic extracts were washed with brine (5 mL), dried over MgSO_4 and concentrated under vacuum. The resulting residue was purified by column chromatography to afford **9** or **10**.

(*E*)-4-(4-Methoxyphenyl)-1-(2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hex-1-en-1-yl)-1H-1,2,3-triazole (**9**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). 110 mg (72%). White solid, mp = 112-116 $^\circ\text{C}$. ^1H NMR (500 MHz, CDCl_3) δ 8.10 (s, 1H), 7.74 (d, J = 8.8 Hz, 2H), 6.96 (d, J = 8.8 Hz, 2H), 3.84 (s, 3H), 2.34 (td, J = 7.6, 1.4 Hz, 2H), 1.54-1.46 (m, 2H), 1.39 (hex, J = 7.4 Hz, 2H), 0.94 (t, J = 7.3 Hz, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 159.7, 147.4, 129.5, 127.2, 123.5, 118.4, 114.4, 84.4, 55.5, 34.3, 31.6, 25.0, 22.5, 14.1. The carbon α to boron was not observed. $^{11}\text{B}\{^1\text{H}\}$ NMR (128 MHz, CDCl_3) δ 30.3. HRMS (ESI+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{21}\text{H}_{31}^{11}\text{BN}_3\text{O}_3$ 384.2458; found 384.2461.

(*E*)-1-(3-Cyclohexyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)prop-1-en-1-yl)-4-(4-methoxyphenyl)-1H-1,2,3-triazole (**10**). 120 mg (71%). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 3/7). White solid, mp: 122-127 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 8.11 (s, 1H), 7.74 (d, J = 8.9 Hz, 2H), 7.23 (s, 1H), 6.96 (d, J = 8.8 Hz, 2H), 3.84 (s, 3H), 2.23 (dd, J = 7.1, 1.0 Hz, 2H), 1.82-1.70 (m, 4H), 1.51-1.43 (m, 1H), 1.33 (s, 12H), 1.25-1.12 (m, 4H), 0.97-0.87 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 159.7, 147.4, 130.1, 127.2, 123.5, 118.4, 114.4, 84.4, 55.5, 42.5, 37.9, 33.4, 26.6, 26.4, 25.0. The carbon α to boron was not observed. $^{11}\text{B}\{^1\text{H}\}$ NMR (128 MHz, CDCl_3) δ 30.1. HRMS (ESI+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{24}\text{H}_{35}^{11}\text{BN}_3\text{O}_3$ 424.2771; found 424.2778.

Access to alkenes 11 or 12 by Suzuki couplings. A solution of compound **9** or **10** (0.4 mmol) in THF (5 mL) and water (0.1 mL) was degassed under argon atmosphere, before addition of [1,1'-bis (diphenyl phosphino) ferrocene] dichloropalladium (II) (5.8 mg, 0.008 mmol), potassium phosphate tribasic monohydrate (277 mg, 1.2 mmol) and *p*-tolylbromide (68 mg, 49 μL , 0.4 mmol). The reaction mixture was heated at reflux in a oil bath for 12 h, cooled to room temperature, diluted with water (5 mL) and extracted with ethyl acetate (2 \times 10 mL). The combined organic extracts were dried over MgSO_4 and evaporated under vacuum. The residue was purified by column chromatography to give the corresponding Suzuki products.

(*Z*)-4-(4-Methoxyphenyl)-1-(2-(*p*-tolyl)hex-1-en-1-yl)-1H-1,2,3-triazole (**11**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 2/8). 86 mg (62%). White solid, mp: 100-102 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.50 (d, J = 8.9 Hz, 2H), 7.25 (s, 1H), 7.19 (dt, J = 7.6, 0.8 Hz, 2H), 7.04 (d, J = 8.1 Hz, 2H), 6.95 (s, 1H), 6.88 (d, J = 8.9 Hz, 1H), 2.51 (td, J = 6.9, 1.4 Hz, 2H), 2.38 (s, 3H), 1.47-1.34 (m, 4H), 0.91 (t, J = 7.1 Hz, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 159.6, 146.7, 138.3, 136.7, 134.6, 130.0, 127.8, 127.2, 123.3, 120.4, 118.3, 114.3, 55.5, 37.3, 29.7, 22.3, 21.4, 14.0. HRMS (ESI+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{22}\text{H}_{26}\text{N}_3\text{O}$ 348.2076; found 348.2070.

(*Z*)-1-(3-Cyclohexyl-2-(*p*-tolyl)prop-1-en-1-yl)-4-(4-methoxyphenyl)-1H-1,2,3-triazole (**12**). The crude product was purified using silica gel column chromatography (EtOAc/hexanes = 2/8). 97 mg (63%). White solid, mp: 108-112 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 7.43 (d, J = 8.8 Hz, 2H), 7.13 (s, 1H), 7.11 (d, J = 7.8 Hz, 2H), 6.96 (d, J = 8.1 Hz, 2H), 6.87 (s, 1H), 6.80 (d, J = 8.8 Hz, 2H), 3.72 (s, 3H), 2.30 (td, J = 7.0, 1.1 Hz, 2H), 2.30 (s, 3H), 1.73-1.50 (m, 5H), 1.26-1.18 (m, 1H), 1.12-1.00 (m, 3H), 0.99-0.83 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 159.6, 146.6, 138.3, 135.1, 134.5, 129.9, 127.7, 127.1, 123.2, 121.1, 118.2, 114.2, 55.4, 45.4, 35.0, 33.2, 26.5, 26.1, 21.4. HRMS (ESI+) m/z ($\text{M}+\text{H}$) $^+$ calcd for $\text{C}_{25}\text{H}_{30}\text{N}_3\text{O}$ 388.2389; found 388.2385.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website.

^1H , ^{13}C , ^{19}F and ^{11}B spectra of compounds **3**, **4**, **7**, **8**, **9**, **10**, **11** and **12** (PDF)

X-ray diffraction data **3ba** and **4ba** (CIF)

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Notes

The authors declare no competing financial interest.

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